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BOTANY REFERENCE NOTES

Paper – I

Angiosperm Systematics: Part - I

Topics covered:

- Taxonomic hierarchy
- International Code of Botanical Nomenclature
- Numerical taxonomy
- Chemotaxonomy
- Evidence from anatomy, embryology and palynology
- Origin and evolution of angiosperms
- Comparative account of various systems of classification of angiosperms

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Angiosperm Systematics

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Taxonomic hierarchy

Hierarchy based classification

Taxonomy is the practice and science of classification based on *degrees of relatedness amongst those being considered.* A hierarchy is an abstract organizational model of inter-level relationships among entities. Hierarchies are useful for organizing and manipulating our knowledge. Hierarchies have been used in biological systematics to represent several distinct, but interrelated, groups. These groups are different facets of the evolution of life.

Hierarchy based classification has also been called *Rank Based Classification*. Accordingly each hierarchical level is also called *Taxonomic Rank.* This rank-based method of classifying living organisms was originally popularized by Linnaeus.

Most important ranks of taxa

According to Art 3.1 of the ICBN the most important ranks of taxa are:

1. Kingdom
2. Phylum or Division
3. Class
4. Order
5. Family
6. Genus
7. Species

Species

The fundamental unit of taxonomy is the species. This is a group of very similar individuals that have the potential to interbreed freely, to produce fertile offspring - but cannot interbreed successfully with individuals from other species.

There are, however, exceptions to this rule in the plant Kingdom, where inter-specific breeding leading to fertile individuals is possible. Still, in the majority of cases, interbreeding of species does not produce fertile offspring.

As in palaeontology it cannot be determined whether a population with a particular morphology was reproductively isolated or not, the definition of a fossil species is based almost entirely on morphological criteria.

The scientific name for a species consists of 2 parts as it is binomial, with a *generic* name followed by a *specific* name, for example, *Mangifera indica.*

Genus

It is the level above the species. In the binomial name for a species, the generic name refers to the genus.

The genus is a group of species that are fairly closely related - such as the genus *Brassica,* which includes several species, such as the *Brassica carinata, B. juncea, B. oleracea, B. napus, B. nigra and B. rapa.* Traditionally, the relatedness of the species within a genus has been establishes using morphological, anatomical, chemical and cytogenetic data but in the recent years genomic relatedness has extensively been relied upon for this purpose.

The generic name always begins with a capital letter.

Family

Genera are grouped into families, which are major groups of generally similar organisms; such as the members of the Family Rosaceae usually have:

1. Woody stems, often with prickles, or trailing stems with runners
2. Usually woody trees, shrubs or climbers
3. Simple or compound leaves, often evergreen
4. Stipules at the base of the leaf
5. Large flowers with five petals or clusters of tiny flowers with five petals
6. Many stamens

The plant family names have their names ending with the termination – *aceae.*

Order

Families are grouped into orders, whose individuals may vary in many ways but retain certain larger similarities.

For example, the order of plants called Coniferales includes cone-bearing gymnosperms dating from the Carboniferous period; most are substantial trees with needle like leaves.

The names of plant orders end with *–ales.*

Class

In biological classification, **class** is a high taxonomic rank, fitting between phylum and order. The composition of each class is determined by a taxonomist.

The level of class was first introduced by a French botanist Joseph Pitton de Tournefort in his classification of plants in 1694 *and* Carolus Linnaeus was the first to use it consistently in his *Systema Naturae* (1735). Since then class had been considered the highest level of the taxonomic hierarchy until ranks called phyla, and divisions were introduced in the nineteenth century.

A class contains several orders showing some larger conserved features. For example, the green algal class Charophyceae has:

1. motile cells asymmetrical
2. two flagella attached in a lateral position in the cell
3. scales common outside sperm cells
4. phragmoplast producing new cross walls after cell division
5. eyespots usually not present
6. glycolate broken down by glycolate oxidase

According to Article *16A.3* of ICBN, a name of a class should end as follows:

a. In the algae: *-phyceae* (class)

b. In the fungi: *-mycetes* (class)

c. In other groups of plants: *-opsida* (class)

Phylum or Division

This is one of the highest taxonomic rank recognized by the ICBN, just below the level of Kingdom. According to Article *16A.1* of ICBN, a name of a division or phylum should end in *-phyta* unless the taxon is a division or phylum of fungi, in which case its name should end in *-mycota.*

Phylum can be explained as grouping organisms based on general body plan, as well as developmental or internal organizations, which do not match with the other groups.

For example, the algal phylum Chlorophyta is characterized by chlorophylls *a* and *b*; starch stored inside chloroplast; mitochondria with flattened cristae; flagella, when present, lack tubular hairs (mastigonemes); unmineralized scales on cells or flagella of flagellates and zoospores.

Kingdom

A kingdom is the highest level of taxonomic rank recognized by the ICBN. However, in modern classifications a further higher group called Domain is now described.

The Kingdom Plantae is defined as a large assemblage of phylogenetically related organisms showing chlorophyll *a* and *b*, embryo formation, plastids that are bound by only two membranes, are capable of storing starch, and cellulose in cell walls.

It can be said that the Kingdom is the largest aggregation of related organisms.

Species and species concept

The species is a fundamental natural unit in biological systematics and there is a universal agreement among the biologists on this matter.

Species is a Latin word meaning "kind" or "appearance." The primary definition of species used most frequently in evolutionary analysis was proposed by biologist Ernst Mayr.

Mayr, in 1963, gave the **Biological Species Concept** which defines species in terms of interbreeding. This biological species concept defines a species as a *population or group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring, but are unable to produce viable, fertile offspring with members of other populations*. In other words, *the members of a biological species are united by being reproductively compatible and at the same time they are reproductively isolated from the members of other species.*

The above definition is widely used and phylogenetically consistent, but it is not always possible to establish reproductive isolation in in the wild and also in a number of other conditions. For these reasons, various other ways have also evolved which establish one species as a distinct group from other species. These approaches are called species concepts. Some important examples are explained below:

1. **Phenetic or Morphological Species Concept:** Taxonomists practically define species by means of morphological or phenetic characters. Phenetic characters are all the observable, or measurable, characters of an organism, including microscopic and physiological characters.

If one group of organisms consistently differs from other organisms, it will be defined as a separate species. The formal definition of the species will be in terms of characters that can be used to recognize the members of that species. The taxonomist who describes the species must have examined specimens of it and of related species, looking for characters that are present in specimens of the species to be described, and absent from other closely related species. These are the characters used to define the species.

Morphological criteria are very important in defining such species which are extinct and represented only by fossils and also such species which reproduce only asexually such as the bacterial species.

2. **Ecological Species Concept:** This concept is applied when reproductive isolation is not possible to establish and there are considerable morphological resemblances between the members of two populations, which the taxonomist presumes to be two closely related but separate species.

   In application of the ecological species concept, the *Principle of Competitive Exclusion* is applied. According to this principle, no two species can have the exactly same ecological niche in a common ecosystem. An ecological niche is made of ecological parameters such as microhabitat, trophic relations, non-trophic biotic relations, periodicity of reproduction and population growth, role in modifying the abiota, role in community etc. In a given ecosystem only a single species can occupy a given niche. This kind of species identification is helpful in identifying species of insects, worms etc. in the wild and the species of bacteria and fungi in culture conditions.

3. **Genetic Species Concept:** It is based on similarity of DNA of individuals or populations. Techniques to compare similarity of DNA include DNA-DNA hybridization, and genetic fingerprinting. This type of similarity analysis is important in establishing many the species of bacteria and fungi in the recent years.

4. **Phylogenetic Species Concept:** A group of organisms that shares an ancestor; a lineage that maintains its integrity with respect to other lineages through both time and space. At some point in the progress of such a group, members may diverge from one another: when such a divergence becomes sufficiently clear, the two populations are regarded as separate species. The parent species goes extinct taxonomically when a new species evolve, the mother and daughter populations now forming two new species.

International Code of Botanical Nomenclature

Introduction to ICBN

Unambiguous names for organisms are essential for effective scientific communication. Names can only be unambiguous if there are internationally accepted rules governing their formation and use. The rules that govern scientific naming in Botany (including Phycology and Mycology) are embodied in the *International Code of Botanical Nomenclature* (ICBN).

The *ICBN* is formulated and changed only by *an International Botanical Congress* (IBC). The IBC is a large-scale meeting of botanists from all over the world. It is authorized by the *International Association of Botanical and Mycological Societies* (IABMS). The International Botanical Congresses are held at intervals of every six years with the venue circulating around the world. The latest was the 18^{th} IBC held in Melbourne, Australia, in July 2011.

Thus, the present edition of the *International Code of Botanical Nomenclature* embodies the decisions of the XVIII International Botanical Congress held in Melbourne in 2011 and therefore it is known as the *Melbourne Code.* It came into force in 2012. It supersedes the *Vienna Code*, published subsequent to the XVII International Botanical Congress in Vienna (2005).

The XIX IBC will be held in Shenzhen, China, in July 2017.

A Brief History of ICBN

In 1813, A.P. de Candolle in his *Theorie Elementaire de la Botanique* gave a detailed set of rules regarding plant nomenclature. However discovery of new plants from later explorations caused concern over procedures for naming these species. Thus, with the passage of time, the need for an international system and rule for naming plants became increasing apparent.

It was then that Alphonse de Candolle, son of A.P. de Candolle convened an assembly of botanists of several countries to present a new set of rules. Candolle convened the First International Botanical Congress held at Paris in 1867. Subsequent meetings of the

International Botanical Congress were held in 1892 (Rochester Code), 1905 (Vienna Code), 1907 (American Code) and 1910, but a general agreement regarding the internationally acceptable rules of plant nomenclature was reached in 1930 at the IBC meeting at Cambridge, UK where for the first time in botanical history, a code of nomenclature came into being that was international in function as well as in name. This code is called the *International Code of Botanical Nomenclature* (ICBN).

The last few IBCs are listed below.

XII	1975	Leningrad	Soviet Union
XIII	1981	Sydney	Australia
XIV	1987	Berlin	Germany
XV	1993	Tokyo	Japan
XVI	1999	St. Louis	United States
XVII	2005	Vienna	Austria
XVIII	2011	Melbourne	Australia

The next XIX IBC will be held in Shenzhen, China, in July 2017.

Principles of ICBN

The Division I of the ICBN document deals with the principles of the botanical nomenclature. It identifies the following six principles.

Principle I Botanical nomenclature is independent of zoological and bacteriological nomenclature. The *Code* applies equally to names of taxonomic groups treated as plants whether or not these groups were originally so treated.

Principle II The application of names of taxonomic groups is determined by means of nomenclatural types.

Principle III The nomenclature of a taxonomic group is based upon priority of publication. (Explanation: In this regard, the *ICBN* sets the formal starting date of plant nomenclature at 1 May 1753, the publication of *Species Plantarum* by Linnaeus or at later dates for specified groups and ranks).

Principle IV Each taxonomic group with a particular circumscription, position, and rank can bear only one correct name, the earliest that is in accordance with the Rules, except in specified cases.

Principle V Scientific names of taxonomic groups are treated as Latin regardless of their derivation.

Principle VI The Rules of nomenclature are retroactive unless expressly limited.

Nomenclatural Types

In biology, a *nomenclatural type* is that which fixes a name to a taxon. Depending on the nomenclature code which is applied to the organism in question, a type may be a specimen, culture, illustration, description or taxon.

The ICBN has greatly emphasized on typification of taxa in order to bring about stabilization of names. The naming of taxonomic groups is determined by means of nomenclatural types. A nomenclatural type is that element, to which the name of a taxon is permanently attached. Following are some of the important nomenclatural types:

1. **Holotype:** It is the one specimen or other element used by the author or designated by him as the nomenclatural type. The holotype is chosen by the original author from a single gathering made by a collector at one time, and expressed definitely at the time of original publication.

2. **Isotype:** An isotype is any duplicate (part of a single gathering made by a collector at a time) of the holotype. For example, if a new species is based on a single gathering that consist of four specimens of the same plant with the same field number placed on four separate herbarium sheets, the original author will designate one of them as a holotype and the remaining three as isotypes.

3. **Paratype:** A paratype is a specimen cited with the original description other than the holotype or isotype. For example, if a new taxon is collected in one season without flowers and fruits and the same taxon is collected in a different season with flowers and fruits, then the two collections will be given different field numbers. Out of these two collections, the author will select one collection

as the holotype and the isotype, while the next gathering cited in the protologues will form the paratype.

4. **Syntype:** A syntype is one of the two or more specimens cited by an author of a species when no holotype was designated, or it is anyone of the two or more specimens originally designated as types.

5. **Lectotype:** It is a specimen or other element selected from the original material to serve as a nomenclatural type when no holotype was designated at the time of publication or as long as it is missing. If the holotype is lost or destroyed, the lectotype is selected from the isotypes, or, when, two or more specimens have been designated as types by the author of a species, the lectotype must be chosen from among these types.

6. **Neotype:** It is a specimen or other element selected to serve as nomenclatural type as long as all of the material on which the name of the taxon was based is missing.

7. **Topotype:** It refers to the specimen collected from the same locality from where the holotype was collected.

The accepted practice of naming the plants

1. Before the middle of the 18^{th} century, plant names were usually polynomials i.e. made up of several words in a series. It was superseded by the binomial system, which was first applied for the plant kingdom by Linnaeus in his *Species Plantarum* in 1753.

2. In the binomial system, a botanical name of a species is a combination of a generic name and a specific epithet. As for example, the botanical name of sunflower is *Helianthus annuus.* The first word *(Helianthus)* designates the genus of the plant, while the second word *(annuus)* designates the species of this genus. The generic name is usually a substantive (noun), while the second term or specific epithet is an adjective or noun.

3. It has been found that the number of published names for the various plants exceeds the actual number of taxa. This is because several names have frequently been attributed to the same taxon. Hence, it is very essential to have a way to decide which of the several names should be selected for a particular taxon. This is where the Principle of Priority comes into play, which insists that each family or taxon of lower rank with particular circumscription, position and rank

can bear only one correct name and each taxon is to be known by the earliest name validly published for the taxon, special exceptions being made for nine families for which alternative names are permitted. Exceptions are also permitted at the family and genus levels, where names are conserved.

4. The new name of a taxon is considered valid or effective for publication, only when it is distributed in a printed form to the general public, or at least to ten well established botanical institutions with libraries accessible to botanists generally. The new name is not considered valid if communicated at a public meeting or by placing of names in collections or gardens open to public or by the issue of microfilm made from manuscripts, typescripts or other unpublished material. Further, the name of a taxon when published has to fulfill certain conditions for validity. Those that have been published on or after 1.1.1935 must be accompanied by a Latin description or diagnosis or by a reference to a previously and effectively published Latin description or diagnosis of the taxon. The name of a new taxon of the rank of family or below that has been published on or after 1.1.1958, is valid only when its nomenclatural type is mentioned along with the name of the place where the type specimen is permanently conserved. Those, that have been published on or after 1.1.1953, are valid only if there is a clear indication of the rank of the taxon and whether it is a new genus *(gen. nov.)*, new species *(sp. nov.)* or a new combination *(comb. nov.)* etc.

5. The name of a taxon (unitary, binary or ternary) is incomplete unless the name of the author or authors who first validly published the name, is cited along with it. This helps in verifying the dates of publication and in imparting precision in biological nomenclature. There are several rules for author citation but usually the names are cited in abbreviated forms but never underlined or typed in Italics, e.g. (1) *Vitex* Linn., (2) *V. trifolia* Linn., (3) *V. trifolia*, var. *simplicifolia* Cham.

6. A hybrid between named taxa may be indicated by placing the multiplication sign between the names of the taxa; the whole expression is then called a hybrid formula. *Ex. 1. Agrostis* × *Polypogon*; *Agrostis stolonifera* × *Polypogon monspeliensis*.

7. The **Chapter V** of the Vienna Code deals with the rejection of names (Art. 51,52, 53, 54, 55, 56, 57, 58). The various rules governing rejection of names are as follows.

   a. A legitimate name must not be rejected merely because it, or its epithet, is inappropriate or disagreeable, or because another is preferable or better known or because it has lost its original meaning. For example, the name *Scilla peruviana* is not to be rejected merely because the species does not grow in Peru.

   b. A name, unless conserved (Art. 14) or sanctioned (Art. 15), is illegitimate and is to be rejected if it was nomenclaturally superfluous when published. For example, the generic name *Cainito* Adans. (1763) is illegitimate because it was a superfluous name for *Chrysophyllum* L. (1753).

   c. A name that was nomenclaturally superfluous when published is not illegitimate on account of its superfluity if it is based on a name-bringing or epithet-bringing synonym (basionym), or if it is based on the stem of a legitimate generic name. When published it is incorrect, but it may become correct later. For example, *Chloris radiata* (L.) Sw. (1788) was nomenclaturally superfluous when published, since Swartz cited *Andropogon fasciculatus* L. (1753) as a synonym. However, it is not illegitimate since it was based on the legitimate *Agrostis radiata* L. (1759). *Chloris radiata* is the correct name in the genus *Chloris* for *Agrostis radiata* when *Andropogon fasciculatus* is treated as a different species, as was done by Hackel.

   d. A name of a family, genus or species, unless conserved or sanctioned, is illegitimate if it is a later homonym, that is, if it is spelled exactly like a name based on a different type that was previously and validly published for a taxon of the same rank. A sanctioned name is illegitimate if it is a later homonym of another sanctioned name.

   e. When two or more generic or specific names based on different types are so similar that they are likely to be confused (because they are applied to related taxa or for any other reason) they are to be treated as homonyms. For example, names treated as homonyms include: *Asterostemma* and *Astrostemma*; *Pleuropetalum* and *Pleuripetalum*.

f. Consideration of homonymy does not extend to the names of taxa not treated as plants. It is however recommended by the Vienna Code that authors naming new taxa under this *Code* should, as far as is practicable, avoid using such names as already exist for zoological and bacteriological taxa.

g. Any name that would cause a disadvantageous nomenclatural change (Art. 14.1) may be proposed for rejection. A name thus rejected, or its basionym if it has one, is placed on a list of *Nomina Utique Rejicienda*. Along with the listed names, all combinations based on them are similarly rejected, and none is to be used.

h. A binary combination in which the specific epithet exactly repeats the generic name is called a *Tautonym* and it leads to rejection.

Numerical taxonomy

Introduction

An overview

A classification method based on the numerical analysis of the variation in a large number of characters of a group of organisms is known as Numerical Taxonomy. It is assumed that classification will be more predictive if the number of characters on which it is based is more.

It is also assumed that, to begin with, each character is of equal weightage although some characters may later be treated to have more weightage. Initially, a matrix of data is compiled of operational taxonomic units (OTU's) against characters so that for every OTU the state of each of perhaps 50 or more characters is recorded.

The matrix can be subjected to a variety of mathematical analyses, which provide a measure of the similarity or dissimilarity between all the OTUs.

The end product is usually one or more dendrograms.

History

Numerical methods in taxonomy are not new. Simple statistical methods like standard deviations, t-tests and chi-squares have been used for several years. The use of computers by taxonomists has established an interesting modem trend called **Numerical Taxonomy** or **Taximetrics.**

Numerical taxonomy provides methods that are objective, explicit and repeatable, and is based on idea put forward by M Adanson (1763). He proposed that a classification should use a vast range of characters covering all aspects of the plants, and in construction of a classification system all characters must be given equal importance. The idea forms the basis of modem numerical taxonomy, also called **Neo-Adansonian classification**.

Principles of Numerical Taxonomy

Numerical taxonomy is based on seven principles:

1. The greater the content of information in the taxa of a classification is and the more characters on which it is based, the better a given classification will be.
2. Every character is of equal weight (*importance*) in creating natural taxa.

3. Overall similarity between any two entities is a function of their individual similarity in each of the many characters for which they are being compared.

4. Distinct taxa can be recognized because correlations of characters differ in the groups of organisms under study.

5. Phylogenetic inferences can be made from the taxonomic structure of a group and from character correlations, given certain assumptions about evolutionary pathways and mechanisms.

6. Taxonomy is viewed and practiced as an empirical science.

7. Classifications are based on phenetic similarity.

Procedure Adopted by Numerical Taxonomy

As organisms are classified on the evidences obtained from their characters, it becomes imperative/essential to employ all the characters for the ideal or a natural classification. But since, each individual may possess thousands of characters it becomes impracticable to use all characters. The number of characters studied in numerical taxonomy are usually about 50-100 from approximately the same or greater number of organisms. It is presumed that the greater the number of characters the more valid the classification is.

The term organism in this field refers to individuals, populations, species, genera or any other taxonomic category and for this reason they are generally called as Operational Taxonomic Units or OTUs.

The different conditions in which the identification characters occur are known as "***character-state***". A particular organ may be absent or present, functional or non-functional. In such simple cases they are said to be two state characters.

Many traits exhibit a number of possible states and so are termed as multistate characters. Both two- state characters and multistate characters may be qualitative or quantitative.

Since numerical taxonomy is an operational science, the procedure is divided into a number of repeatable steps allowing the results to be checked at every step.

Choice of units to be studied: First step is to decide what kind of units to study. In numerical taxonomy, the basic unit of study is called the "*Operational Taxonomic Unit*". Thus, the OTU can be an individual plant if the taxonomist is studying a single population of plants to find out the range of variation in its characters. Similarly, one may treat an entire population of plants as an OTU if the study is on a single species represented by different populations existing in nature; or the OTU may be different species when a genus is

evaluated. Therefore, in numerical taxonomy, the OTU varies with the material being studied, and this helps the taxonomists in making an objective study.

Selection of Characters (Attributes): After selecting the OTUs it is necessary to select characters by which they are to be classified. The characters, which vary greatly amongst the OTUs, are clearly more useful in numerical taxonomy. A sufficiently large number of suitable characters are selected. It is usually recommended that not less than 50 characters should be used. Preferably a minimum of 60 and generally 80 to 100 or more characters are needed to produce a fairly stable and reliable classification. According to Sneath and Sokal (1977) these characters should be from all parts and all the stages of life cycle. The selected characters have to be coded or given some symbol or mark.

Binary coding or two-state coding: This is the simplest form of coding adapted in numerical Taxonomy where the characters are divided into + and - or as 1 and 0. The positive characters are recorded as + or 1 and the negative characters as - or 0. It is possible to use this method of coding for all characters studied. In case a particular character is not present in an OTU being examined, the symbol or code NC is used, indicating that there is no comparison for that character.

Character states	*A*	*B*	*C*	*D*
1	+	+	+	NC
2	+	+	+	+
3	+	+	+	–
4	–	+	NC	NC
5	+	+	NC	+
6	+	+	+	+
7	+	+	+	NC
8	NC	–	+	+
9	+	+	+	+
10	+	+	+	+

Multi-state Coding Method

A character having three or more different states:

Qualitative multi-state characters - They possess three or more contrasting forms each ranking equal. They can be analysed in two ways:

1. To convert them to a series of binaries or
2. Each entity is offered a choice of one of n series (n=number of states assumed by the attribute). The degree of similarity is measured in terms of dissimilarity, i.e. less dissimilar entities are more similar.

Quantitative multi-state characters represent measures of size of a continuous scale such as weight or length. They can be recorded into several two-state characters or arbitrarily dividing the scale into two parts that need not necessarily be equally long. However, all the characters selected are given equal weight when creating taxonomic groups. Data processing is to estimate the similarity between pairs of OTUs and the basic data are recorded in a data matrix.

Data Matrix is tabulation of the data, such as taxonomic characters, to show difference between categories (taxa) often in a machine-readable form. Data matrix is also known as comparison chart, data chart, data table etc.

Once the OTUs have been selected and character-states and their subsequent coding has been determined, the data is presented in the form of primary data matrix or t.n matrix where 't' represents the OTUs and 'n' the characters

If we have used 50 OTUs and scored 100 characters from each, then we will obtain 50x100=5,000 units of information. Thus, the large amount of information obtained makes the use of computers almost absolutely necessary in numerical taxonomy.

Measurement of Similarity—There are many methods for estimating the phenetic resemblance (*similarity*) between the taxonomic entities analysed .Overall similarity is calculated by comparing each OTU with every other and is usually expressed as a percentage, 100 percent S for identical and 0 per cent for no resemblance. A similarity table or matrix is then constructed by tabulating the S coefficients for each one of the OTU. The simplest form of Coefficient of Associations used by Sneath (1957) is a numerical index-S for similarity between each pair of organisms examined. It is derived as S= N_s / N_s + N_d where where N_s stands for the number of +ve features shared by any 2 OTUs and N_d stands for number of features +ve in one OUT and –ve in the other.

OTUs	*A*	*B*	*C* (*OTUs*)	*D*	*E* →
A	100				
B	90	100			
C	60	60	100		
D	57	50	50	100	
E ↓	90	90	60	58	100

Similarity index is a measure of the similarity in species composition of the communities such as Jaccard's coefficient, Kulezinski's coefficient, and Sorensen's coefficient. Similarity coefficient is a measure of the association of character states of two specimens or taxa.

Jaccard's coefficient is a measure of the similarity in species composition between two communities (A and B) calculated as Si=C/a+b+c where C the number of species common to both, and a and b are the number of species occurring only in communities A and B respectively.

Kulezinski's coefficient is an index of similarity in species composition between two communities (A and B) which is relatively little influenced by dissimilar sample sizes; calculated as Sk=C (a+b) where C is the number of species common to both; a and b are the number occurring in communities A and B respectively.

Sorensen coefficient (Sorensen index). Here 'S' is a measure of the similarity between species composition of two communities, calculated as 2C/a + b where a and b are the number of species in communities A and B respectively and C the number common to both; usually expressed as a percentage.

Gower (1971) has proposed a general coefficient of similarity applicable to mixed qualitative and quantitative characters

Gower coefficient	$(GS) = \dfrac{\sum^{n} Sijk}{n}$

where *'Sijk'* is a score on character i for comparison of OTUs J and K such that *Sijk*- 1-(lx-xl/R) Here R is the range of character i in overall *t* OTUs. If all characters are qualitative (1,0) then SG becomes 'S'.

Taxonomic Distance (d) is an expression of the relationship between individuals or taxa in terms of multidimensional space, where each dimension represents a character, based on quantitative estimates of dissimilarity.

Large Scale Scientific computation

The increasing speed of computers and advances in numerical methods have made it possible to solve most small problems rapidly by means of readily available software, and the attention of many numerical analysts has turned to the solution of problems so large that they require inordinate amount of computer time.

A variety of clustering methods have been employed in numerical taxonomy including sequential, agglomerative, and hierarchic and nonoverlapping clustering.

Dendrogram: Dendrograms are most commonly employed to represent taxonomic structure resulting from cluster analysis. These have the advantage of being readily interpretable as conventional taxonomic hierarchies.

Once similarity has been calculated various techniques are adopted to group the taxa. First we group those taxa, which are at least distance to form groups and then proceed to form groups of groups, and a structure formed by this method is known as a dendrogram or phenogram.

Advantages and limitation

Advantages

1. Numerical taxonomy has the power to integrate data from the variety of sources, such as morphology, physiology, chemistry, affinities between DNA strands, amino acid sequences or proteins and more. This is very difficult to do by conventional taxonomy.

2. Greater efficiency is promoted through the automation of large portion of the taxonomic process. Thus, less highly skilled workers or automation can do much highly specialized work.

3. The data coded in numerical form can be integrated with existing electronic data processing system in taxonomic institutions and used for the creation of description, keys, catalogues, maps and other documents.

4. The methods, being quantitative, provide greater description along the spectrum of taxonomic difference and are more sensitive in delimiting taxa. They should give better classifications and keys than can be obtained by conventional methods.

5. The creation of explicit data tables for numerical taxonomy has forced workers in this field to use more and better-described characters. This necessarily will improve the quality of conventional taxonomy as well.

6. A fundamental advantage of numerical taxonomy has been the re-examination of the principles of taxonomy and of the purposes of classification. This has benefited taxonomy in general, and has led to the posing of some basic questions.

7. Numerical taxonomy has led to the re-interpretation of a number of biological concepts and to the raising of new biological and evolutionary questions.

8. Examples of studies made by numerical methods are *Apocynum* (Apocynaceae), *Cucurbita* and hybrids (Cucurbitaceae), *Crotalaria* (Fabaceae), *Salix* (Salicaceae),

Lamiaceae, Verbenaceae and allied families. *Zinnia* (Asteraceae), *Silene* (Caryophyllaceae), *Quercus* (Fagaceae), *Oenothera* (Onagraceae), *Solanum* (Solanaceae), wheat cultivars, Poaceae, Bromeliaceae, Maize cultivars, barley cultivars and hybrids (Sneath and Sokal 1973).

Disadvantages

1. For the believers of "***Biological Species Concept***" numerical species recognized by this method is unacceptable unless some "genetic" or "***crossability***" evidences are incorporated.
2. Orthodox taxonomists feel that they are more successful than a mechanical computer fed with non-relevant selection of characters.
3. Selection of characters also poses problems.

Chemotaxonomy

Chemotaxonomy is the method of biological classification based on similarities in the structure of certain compounds among the organisms being classified.

John Griffith Vaughan was one of the pioneers of chemotaxonomy.

Chemotaxonomy of plants is an expanding field of study and seeks to utilize chemical information to improve upon the classification of plants.

A large variety of chemical compounds are found in plants and quite often the biosynthetic pathways producing these compounds differ in various plant groups. In many instances the biosynthetic pathways correspond well with existing schemes of classification based on morphology. In other cases, the results are at variance, thus calling for revision of such schemes. The natural chemical constituents are conveniently divided as under:

1. ***Micromolecules***: Compounds with low molecular weight (less than 1000 Dalton).
    a. **Primary metabolites:** Compounds involved in vital metabolic pathways—citric acid, aconitic acid, protein amino acids, etc.
    b. **Secondary metabolites:** Compounds which are the byproducts of metabolism and often perform non-vital functions—non-protein amino acids, phenolic compounds, alkaloids, glucosinolates, terpenes, etc.
2. ***Macromolecules***: Compounds with high molecular weight (1000 Dalton or more).
    a. **Non-semantide macromolecnles:** Compounds not involved in information transfer—starches, celluloses, etc.
    b. **Semantides:** Information carrying molecules—DNA, RNA and proteins.

The utilization of studies on DNA and RNA for understanding of phylogenetic relations has received a great boost over the last decade, meriting the establishment of a new field referred to as **Molecular Systematics,** and would be dealt separately after chemotaxonomy. Only proteins would be described in this section.

Primary metabolites

Primary metabolites include compounds, which are involved in vital metabolic pathways. Most of them are universal in plants and of little taxonomic importance. The quantitative variations of these primary metabolites may, however, be of taxonomic significance sometimes. In *Gilgiochloa indurata* (Poaceae), **alanine** is the main amino acid in leaf

extracts, **proline** in seed extracts and **asparagine** in flower extracts. Rosaceae is similarly rich in arginine.

Secondary metabolites

Secondary metabolites perform non-vital functions and are less widespread in plants as compared to primary metabolites. These are generally the byproducts of metabolism. They were earlier considered to be waste products, having no important role. Recently, however, it was realized that they are important in chemical defense against predators, pathogens, allelopathic agents and also help in pollination and dispersal (*Swain, 1977*). Gershenzon and Mabry (1983) have provided a comprehensive review of the significance of secondary metabolites in higher classification of angiosperms. The following major categories of secondary metabolites are of taxonomic significance:

NON-PROTEIN AMINO ACIDS

A large number of amino acids not associated with proteins are known (more than 300 or so). Their distribution is not universal but specific to certain groups and, as such, holds promise for taxonomic significance. **Lathyrine** is, thus, known only from *Lathyrus.* **Canavanine** occurs only in Fabaceae and is shown to be a protection against insect larvae. These amino acids are usually concentrated in storage roots and, as such, root extracts are generally used for their study.

PHENOLICS

Phenolic compounds form a loose class of compounds, based upon a phenol (C_6H_5OH). **Simple phenols** are made of a single ring and differ in position and number of OH groups. These are widely distributed in the plant kingdom; common examples catechol, hydroquinone, phloroglucinol and pyrogallol. Coumarins, a group of natural phenolics, have a characteristic smell. The crushed leaves of *Anthoxanthum odoratum* can thus be identified by this characteristic odour.

Flavonoids, the more extensively studied compounds, are based on a flavonoid nucleus consisting of two benzene rings joined by a C3 open or closed structure. Common examples are flavonols, isoflavones, malvadins, and anthocyanadins (often combining with different sugars and at different places to form various types of anthocyanins). **Anthocyanins** and **Anthoxanthins** are important pigments in the cell sap of petals providing red, blue (anthocyanins), and yellow (anthoxanthins) colours in a large number of families of angiosperms.

These pigments are absent in some families and replaced by highly different compounds, **betacyanins** and **betaxanthins** (together known as **betalains),** which consist of heterocyclic nitrogen-containing rings and having quite distinct metabolic pathways of synthesis. However, they carry the same functions as anthocyanins. Betalains are mutually exclusive with anthocyanins, and concentrated in the traditional group Centrospermae of Engler and Prantl, now recognized as order Caiyophyllales. Of the nine families which contain betalains, seven were included in Centrospermae, Cactaceae placed in Cactales or Opuntiales and the ninth was placed in Sapindales.

The technique of two-directional paper chromatography, which brings about a more pronounced separation of flavonoids, has proved very useful in taxonomic studies.

Hymenophyton (Biyophytes) was considered by some researchers to be a monotypic genus, but by others to include two species. Markham et al., (1976) on the basis of rapid flavonoid extraction, two-dimensional chromatographic analysis and identification concluded that the genus contains two distinct species, *H. leptodotum* and *H. Jlabellatum,* and that there is no justification for their merger.

Similar studies in the genus *Baptisia* (Fabaceae) by Alston and Turner (1963) have been very useful in the detection of hybridization. Each species of the genus has a distinctive spectrum of flavonoids, and the hybrid can be easily identified by the combination of flavonoid pattern of both parental species in the suspected hybrid.

ALKALOIDS

Alkaloids are organic nitrogen-containing bases, usually with a heterocyclic ring of some kind. **Nicotine** (*Nicotiana*) and **ephedrine** (*Ephedra*) are familiar examples. Their distribution is often specific and thus taxonomically significant. **Morphine** is present only in opium poppy (*Papaver somniferum*). Mears and Mabry (1971), in studies conducted on the family Fabaceae, observed that the alkaloid **hystrine** occurs only in three genera *Genista, Adenocarpus* (both belonging to Genistae) and *Ammodendron* (originally placed in Sophorae). The latter, however, lacks **matrine,** characteristic of Sophorae. This indicates that the transfer of the last genus also to Genistae is warranted. Families Papaveraceae and Fumariaceae are closely related. This affinity is supported by the occurrence of the alkaloid **protopine** in both.

GLUCOSINOLALTES

Glucosinolates are mustard oil glucosides found in the order Capparales. Originally Cruciferae, Capparaceae, Papaveraceae and Fumariaceae were placed in the same order,

Rhoeadales. Chemical and other evidence, however, supported the placement of Cruciferae and Capparaceae in the order Capparales (on the basis of the presence of glucosinolates) and Papaveraceae and Fumariaceae in the order Papaverales—or suborder Papaverineae of Ranunculales (Thorne, 2003) —(on the basis of the absence of glucosinolates and the presence of the alkaloid benzylisoquinolene).

Bataceae and Gyrostemonaceae were once placed in Centrospermae (Caryophyllales) but subsequently removed due to the absence of betalains. This removal was supported by the presence of glucosinolates, which are absent in Caiyophyllales.

TERPENES

Terpenes include a large group of compounds derived from the mevalonic acid precursor and are mostly polymerized isoprene derivatives. Common examples are **camphor** [*Cinnamomam*], **menthol** (*Mentha),* and **carotenoids.** They seem to have a definite role in the allelopathic effects of plants.

Terpenoids, the common group of terpenes, have been largely used in distinguishing specific and subspecific entities, geographic races and detection of hybrids. This has been largely possible by the technique of gas chromatography, enabling qualitative as well as quantitative measure of chemical differences. Studies in *Citrus* have focused on determination of the origin of certain cultivars. Studies on *Juniperus viginiana* and *J. ashei* have refuted previous hypotheses about extensive hybridization and introgression between the two species. Their distribution in *Pinus* has been used (Mirov, 1961) to understand relationships. *P.jeffreyi* has been considered a variety of *P. ponderosa,* but terpentine distribution showed that it strongly resembles the group Macrocarpae and not Australes to which P. *ponderosa* belongs.

A major contribution of terpenoid chemistry has been the use of **sesquiterpene lactones** in the family Compositae. Many tribes within the family are characterized by distinct types of sesquiterpene lactones they produce. This helped to establish that genus *Vemonia* has two centres of distribution—one in the Neotropics and the other in Africa. Similarly, studies on *Xanthium strumarium* (McMillan et al., 1976) have thrown some light on the origin of Old World and New World populations.

Iridoids constitute another important group of terpenes (mostly monoterpene lactones). They are present in over 50 families and their presence is correlated with sympetaly, unitegmic tenuinucellate ovules, cellular endosperm and endosperm haustoria. Assuming that 'independent origin of several groups with this combination of independent attributes is unlikely', Dahlgren brought together all iridoid-producing families. The occurrence of iridoids

in several unrelated families, e.g. Hamamelidaceae and Meliaceae, however, suggests that iridoids could have arisen independently several times in the evolution of angiosperms. The occurrence of a distinctive iridoid **aucubin** in *Budleia* has been taken to support its transfer from Loganiaceae to Budleiaceae.

Macromolecules

In addition to DNA and RNA, which will be dealt under Molecular systematics, the macromolecules include proteins, and complex polysaccharides such as starches and celluloses. Starches are commonly found in the form of grains which may be concentric (*Triticum*, *Zea*) or eccentric (*Solarium tuberosum*) and present anatomical characteristics which can be seen under a microscope. Detailed studies of starch grains under SEM also hold promise for taxonomic significance.

Proteins

Proteins, together with nucleic acids, are often called Semantides, which are primaiy constituents of living organisms and are involved in information transfer. Based on their position in the information transfer DNA is a **primary semantide,** RNA **secondary semantide** and proteins the **tertiary semantides.**

Semantides are popular sources of taxonomic information, and most of this information has come from proteins. The information about DNA and RNA will be discussed under Molecular Systematics in the next section; only proteins are being discussed here.

Proteins are complex macromolecules made up of amino acids linked into a chain by peptide bond, thus forming a **polypeptide chain**, organized into a three dimensional structure. Because of their complex structure, special techniques are necessary for the isolation, study and comparison of proteins.

These methods include **serology, electrophoresis** and **amino acid sequencing.**

Anatomy in relation to Taxonomy

Introduction

Anatomical features have played an increasingly important role in elucidation of phylogenetic relationships. Anatomical characteristics are investigated with the help of a light microscope; whereas ultrastructure (finer details of contents) and micromorphology (finer details of surface features) are brought out using an electron microscope. Anatomical work of taxonomic significance was largely undertaken by Bailey and his students. Carlquist (1996) has discussed the trends of xylem evolution, especially in the context of primitive angiosperms.

Anatomical features and their application in systematics

Wood anatomy

1. Vessels are absent in Gymnosperms, but present in Angiosperms. It is commonly believed that there has been a progressive evolution in angiosperms from tracheids to long, narrow vessel elements with slanted, scalariform perforation plates, to short, broad vessel elements with simple perforation plates. **Studies on wood anatomy have contributed largely in arriving at the conclusion that Amentiferae constitute a relatively advanced group, and that Gnetales are not ancestral to angiosperms.**

2. Demonstration of vessel-less angiosperms (Winteraceae, Trochodendraceae), also having other primitive features, has led to the conclusion that angiosperm ancestors were vessel-less.

3. The separation of *Paeonia* into a distinct family Paeoniaceae and Austrobaileya into a separate family Austrobaileyaceae has been supported by studies of wood anatomy.

Nodal anatomy

1. Nodal anatomy has considerable significance in angiosperm systematics. The number of vascular traces entering leaf base and associated gaps (lacunae) left in the vascular cylinder of stem at each node are distinctive for several groups.
2. The genus Illicium has been separated from Winteraceae because of unilacunar nodes, continuous pseudosiphonostele and the absence of granular material in stomatal depressions.

Leaf anatomy

1. In **Poaceae**, leaf anatomy has been of special taxonomic help. The occurrence of the C-4 pathway and its association with Kranz anatomy (dense thick-walled chlorenchymatous bundle sheath, mesophyll simple), has resulted in revised classification of several genera of grasses.
2. Melville (1962, 1983) developed his gonophyll theory largely on the basis of the study of venation pattern of leaves and floral parts.
3. The rejection of *Sanmiguelia* and *Furcula* as angiosperm fossils from the Triassic has largely been on the basis of detailed study of the venation pattern of leaves (Hickey and Doyle, 1977).
4. The more recent rediscovery of *Sanmiguelia* from the Upper Triassic of Texas (Cornet 1986, 1989) points to presumed angiosperm ancestor incorporating features of both monocots and dicots.
5. Discovery of the Late Triassic *Pannaulika* (Cornet) from the Virginia-North Carolina border has reopened the possibilities of Triassic origin of angiosperms.

Trichomes

1. Trichomes constitute appendages of epidermis which may be non-glandular or glandular.
2. Non-glandular trichomes may be in the form of simple unicellular or multicellular hairs (common in Brassicaceae, Lauraceae and Moraceae), in the form of vesicles, peltate hairs (*Olea*) or flattened scales.
3. Branched hairs may be dendroid, stellate (*Styrax*) or candelabrum-like (*Verbascum*). Glandular trichomes may be sessile or stalked and present a variety of forms.

4. Unicellular glandular hairs of *Atriplex* are bladder-like with few-celled stalk and basal cell and they secrete salt. Others may secrete nectar (calyx of Abutilon), mucilage (leaf base of *Rheum* and *Rumex*).

5. Various types of trichomes and their distribution is shown in Figures 1 and 2.

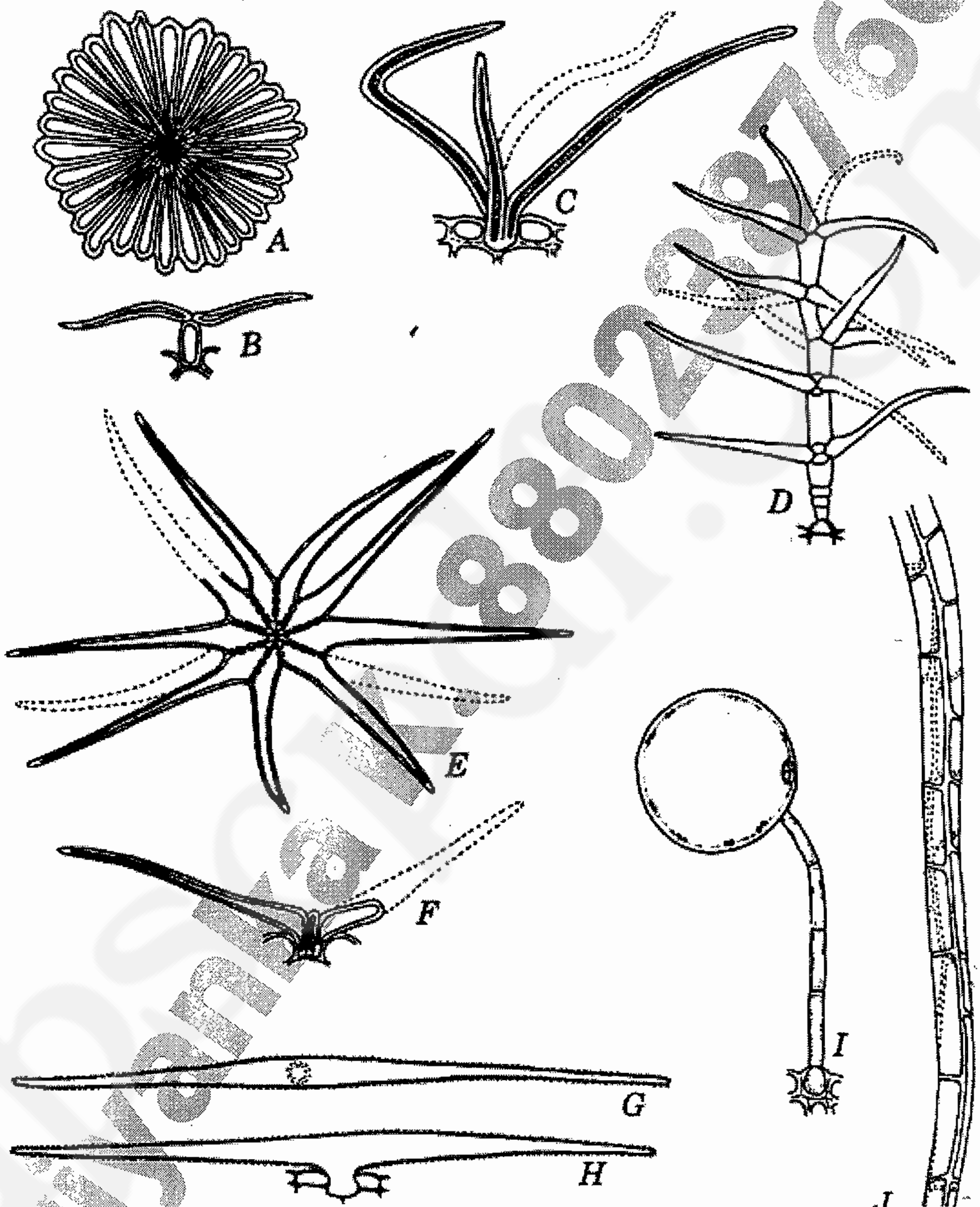


Figure 1: Various types of trichomes: A, B, peltate scale of *Olea* in surface (A) and side (B) views. C, tufted hair of *Quercus*. D, branched hair of *Platanus*. E, F, stellate hair of *Sida* in surface (E) and side (F) views. G, H, two-armed, T-shaped unicenular hair of *Lobularia* in surface (G) and side (H) views. I, vesiculate hair of *Chenopodium*. J, part of multicellular shaggy hair of *Portulaca*.

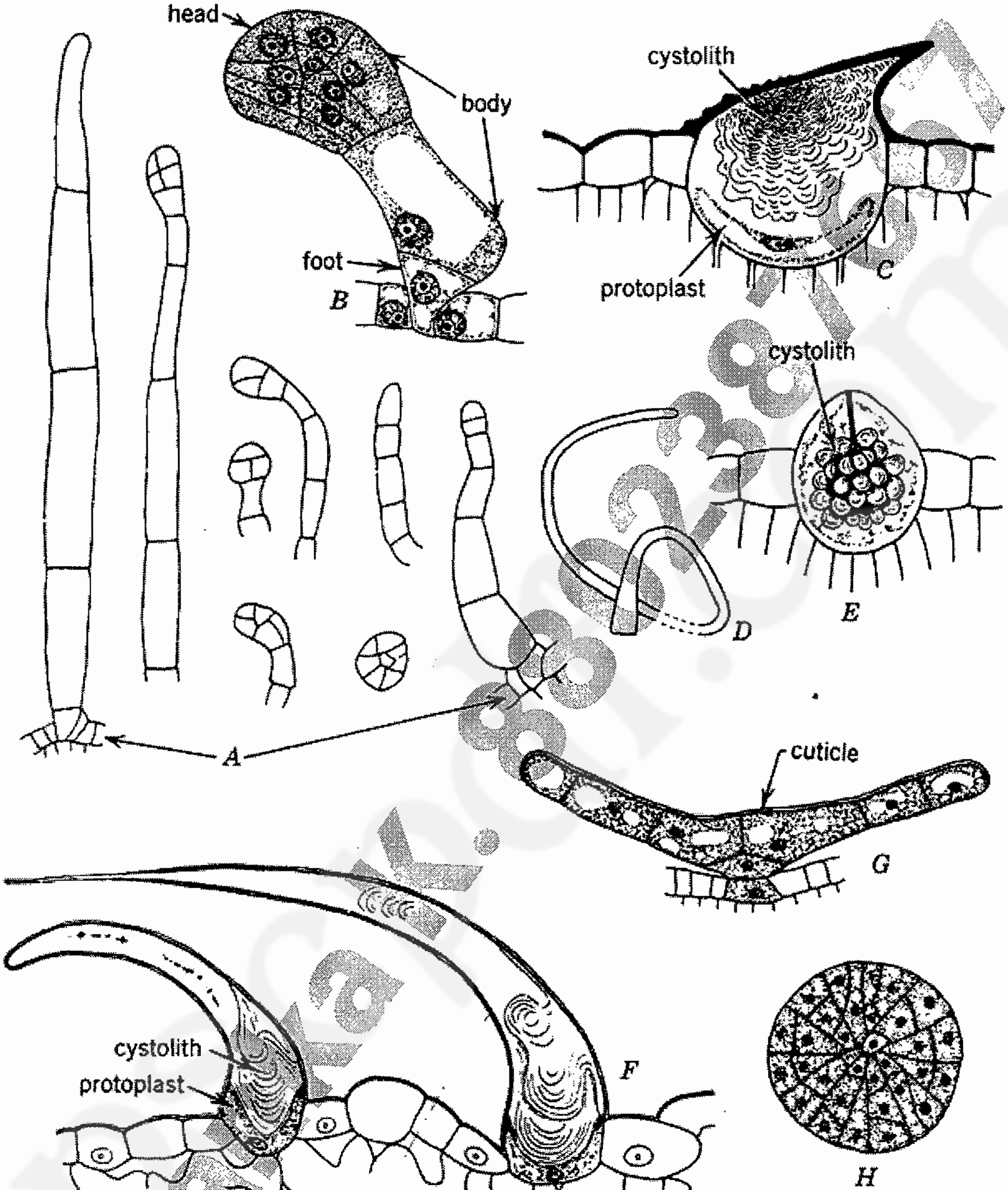


Figure 2: Trichomes in various forms: A, group of ordinary and glandular (with multicellular heads) hairs of *Nicotiana* (tobacco). B, enlarged view of glandular hair of tobacco, C, hooked hair with cystolith of *Humulus*. D, long coiled unicellular hair, and E, short bristle with cystolith of *Boehmeria*. F, hooked hairs with cystoliths of *Cannabis* G, H, glandular peltate trichome of *Humulus* seen in sectional (G) and surface (H) views.

Epidermal features

1. Epidermal features are also of considerable taxonomic interest. Prat (1960) demonstrated that one can distinguish a Festucoid type (simple silica cells, no bicellular hairs) and Panicoid type (complicated silica cells, bicellular hairs) of epidermis in grasses.
2. Stace (1989) lists 35 types of stomata in vascular plants. Closely related families Acanthaceae and Scrophulariaceae are distinguished by the presence of diacytic stomata in the former as against anomocytic in the latter.

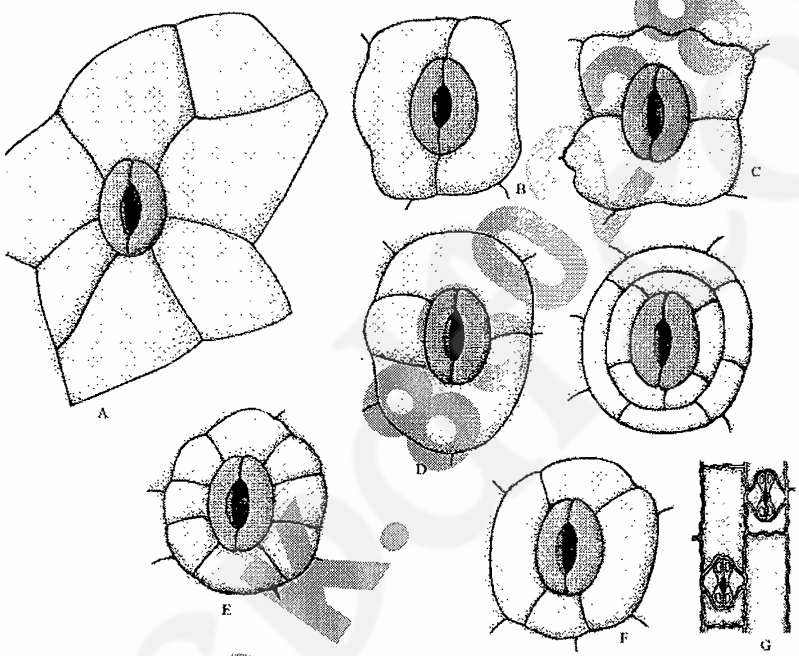


Figure 3: Stomatal apparatus in Angiosperms. A: Anomocytic type with epidermal cells around stomata not differentiated; B: Paracytic type with two or more cells parallel to the guard cells differentiated as subsidiary cells; C: Diacytic type with two subsidiary cells at right angles to the guards cells; D: Anisocytic type with three subsidiary cells of unequal size; E: Actinocytic type with stomata surrounded by a circle of radiating cells; F: Tetracytic type with four subsidiary cells; G: Cyclocytic type with concentric rings of subsidiary cells; H: Graminaceous type with dumb-bell shaped guard cells with two small subsidiary cells parallel to the guard cells.

3. **Stomatal types** (Figure 3) are distinctive of certain families such as Ranunculaceae (anomocytic), Brassicaceae (anisocytic), Caryophyllaceae (diacytic), Rubiaceae (paracytic), and Poaceae (graminaceous). Anomocytic type has ordinary epidermal surrounding the stomata. In others the epidermal cells surrounding the stomata are differentiated as subsidiary cells. There may be two subsidiary cells at right angles to the guard cells (diacytic), two are more parallel to the guard cells (paracytic), or three subsidiary cells of unequal size (anisocytic). Other types include actinocytic type with

stomata surrounded by a ring of radiating cells, cyclocytic with more than one concentric rings of subsidiary cells and tetracytic with four subsidiary cells. The stomatal complex of Poaceae is distinctive in having two dumb-bell shaped guard cells with two small subsidiary cells parallel to the guard cells.

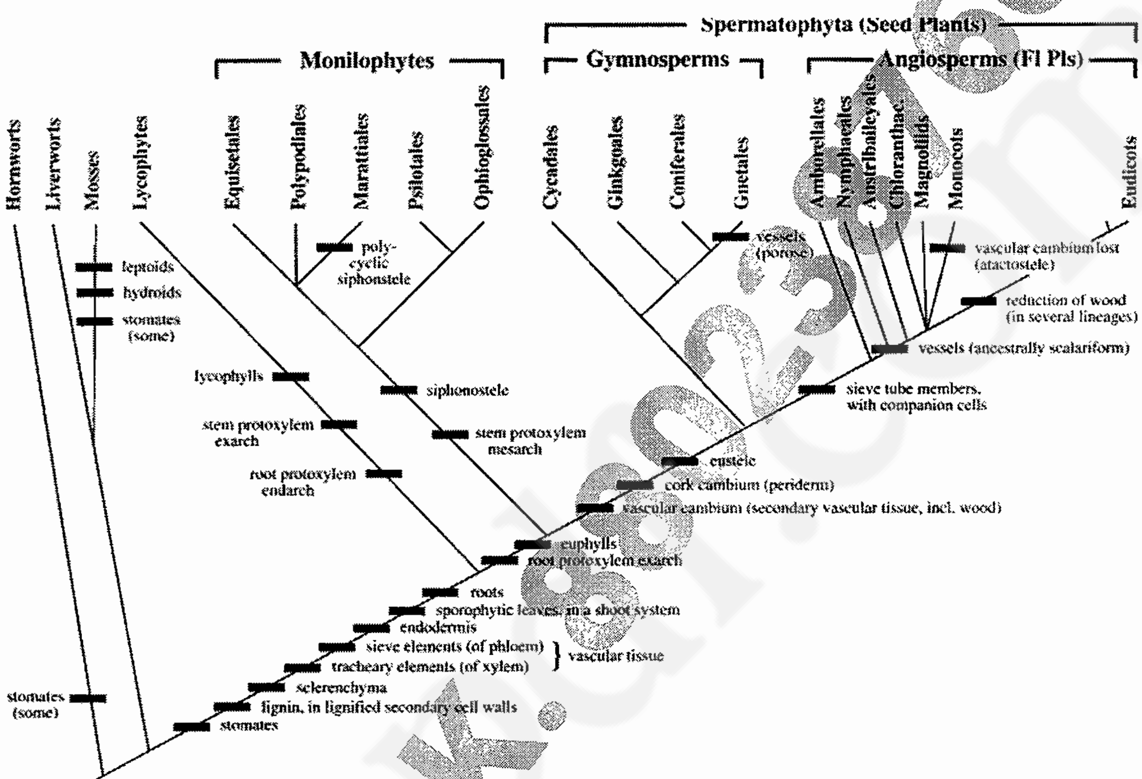


Figure 4: Summary cladogram of Land Plants, showing major anatomical apomorphies

Embryology in relation to Taxonomy

Embryology has made a relatively lesser contribution in understanding taxonomic affinities. This is primarily because of long preparatory work needed for embryological studies. More often, the study of hundreds of preparations may reveal just a single embryological characteristic of any significance. It may take many years of laborious and painstaking research to study even a few representatives of a family. The embryological features of major significance include microsporogenesis, development and structure of ovule, embryo sac development, endosperm and embryo development.

Families marked out by distinct embryological features

A number of families of angiosperms are characterized by unique embryological features found in all members. These include:

Podostemaceae

Family Podostemaceae includes perennial aquatic herbs, which have a unique embryological feature in the formation of a pseudoembryo sac due to the disintegration of the nucellar tissue. The family is also characterized by the occurrence of pollen grains in pairs, bitegmic tenuinucellate ovules, bisporic embryo sac, solanad type of embryogeny, prominent suspensor haustoria, and absence of triple fusion and, consequently, endosperm.

Cyperaceae

Family Cyperaceae is characterized by the formation of only one microspore per microspore mother cell. Following meiosis, of the four microspore nuclei formed, only one gives rise to pollen grain. Besides Cyperaceae, only Epacridaceae in a few members shows the degeneration of three microspore nuclei. Cyperaceae is distinct from these taxa in pollen shedding at the 3celled stage, as against the 2-celled stage shedding in Epacridaceae.

Onagraceae

Family Onagraceae is characterized by Oenothera type of embryo sac, not found in any other family except as an abnormality. This type of embryo sac is 4-nucleate and is derived from the micropylar megaspore of the tetrad formed.

Specific examples of the role of embryological data

There are a few examples of the embryological data having been very useful in the interpretation of taxonomic affinities:

Trapa

The genus *Trapa* was earlier (Bentham and Hooker, 1883) included under the family Onagraceae. It was subsequently removed to the family Trapaceae (Engler and Diels, 1936;

Hutchinson, 1959, 1973) on the basis of distinct aquatic habit, two types of leaves, swollen petiole, semiepigynous disc and spiny fruit. The following embryological features support this separation: (i) pyramidal pollen grains with 3 folded crests (bluntly triangular and basin shaped in Onagraceae); (ii) ovary semi-inferior, bilocular with single ovule in each loculus (not inferior, trilocular, with many ovules); (iii) Polygonum type of embryo sac (not Oenothera type); (iv) endosperm absent (not present and nuclear); (v) embryo Solanad type (not Onagrad type); (vi) one cotyledon extremely reduced (both not equal); and (vii) fruit large one-seeded drupe (not loculicidal capsule).

Paeonia

The genus *Paeonia* was earlier included under the family Ranunculaceae (Bentham and Hooker; Engler and Prantl). Worsdell (1908) suggested its removal to a distinct family, Paeoniaceae. This was supported on the basis of centrifugal stamens (Corner, 1946), floral anatomy (Eames, 1961) and chromosomal information (Gregory, 1941). The genus as such has been placed in a distinct monogeneric family, Paeoniaceae, in all modern systems of classification. The separation is supported by the following embryological features: (i) centrifugal stamens (not centripetal); (ii) pollen with reticulately-pitted exine with a large generative cell (not granular, papillate and smooth, small generative cell); (iii) unique embryogeny in which early divisions are free nuclear forming a coenocytic stage, later only the peripheral part becomes cellular (not onagrad or solanad type); and (iv) seed arillate.

Exocarpos

The genus *Exocarpos* (sometimes misspelled Exocarpus) is traditionally placed under the family Santalaceae. Gagnepain and Boureau (1947) suggested its removal to a distinct family Exocarpaceae near Taxaceae under Gymnosperms on the basis of articulate pedicel, 'naked ovule' and presence of a pollen chamber. Ram (1959) studied the embryology of this genus and concluded that the flower shows the usual 156 Plant Systematics

angiospermous character, the anther has a distinct endothecium and glandular tapetum, pollen grains shed at the 2-celled stage, embryo sac of the Polygonum type, endosperm cellular, and the division of zygote transverse. This confirms that the genus Exocarpos is undoubtedly an angiosperm, and a member of the family Santalaceae, with no justification for its removal to a distinct family. The genus is as such placed in Santalaceae in all the major systems of classification.

Loranthaceae

The family Loranthaceae is traditionally divided into two subfamilies—Loranthoideae and Viscoideae—largely on the basis of presence of a calyculus below the perianth in the former and its absence in the latter. Maheshwari (1964) noted that the Loranthoideae has triradiate pollen grains, Polygonum type of embryo sac, early embryogeny is biseriate, embryo suspensor present, and viscid layer outside the vascular supply in fruit. As against this, Viscoideae have spherical pollen grains, *Allium* type of embryo sac, early embryogeny many tiered, embryo suspensor absent, and viscid layer inside the vascular supply of fruit. He thus advocated separation of the two as distinct families Loranthaceae and Viscaceae. The separation was accepted by Takhtajan (1980, 1987, 1997), Dahlgren (1980), Cronquist (1981, 1988) and Thorne (1981, 1992).

Palynology in relation to Taxonomy

Palynological features of taxonomic interest

The term Palynology was first used by Hyde and Williams in 1944; they defined it as "the study of pollen and pollen and other spores and their dispersal, and applications thereof."

Pollen morphology offers reliable data and evidence of taxonomic relationships. The taxonomic and evolutionary importance of pollen morphology may be at specific, generic or higher levels.

Palynological evidence may be used to:

(1) place taxa of uncertain affinities

(2) to suggest rearrangements

(3) withdrawals and separations

(4) corroborating other lines of evidence

Sometimes, the study of fine structural details in fossil pollen opens up possibility of new sources of phylogenetic evidence.

The major characters of pollen grains that are used in solving taxonomic and phylogenetic problems are:

(1) Apertural patterns

(2) Exine stratification and ornamentation

(3) Pollen association and

(4) Pollen nuclear number

Stenopalynous and Eurypalynous | The concept of stability of palynological features in a taxon

(1) In many cases, the type of pollen of a taxon is characteristic and constant; such a taxon is called **Stenopalynous** or unipalynous and may be exclusive of that group, e.g., thick walled pollen grains of the Gyrostemonacee of Australia. Stenopalynous

taxa are generally considered to be very close phylogenetic groupings. Ascelpiadaceac, Asteraceae, Poaceae, Brassicaceae and Lamiaceae are some of the stenopalynous families.

(2) In other cases, the types of pollen may vary considerably in size, aperture, stratification of exine etc. Such taxa are termed **eurypalynous** or multipalynous. Eurypalynous condition, seen in Malvaceae, is considered primitive. The family Euphorbiaccae is a unique example of eurypalyny in angiosperms. According to Webster (1994) the pollen grains in the family are so diverse, that only Acanthaceae can rival it.

Examples of Palynological data being used in taxonomy

Apertural Patterns in taxonomic applications

By using the NPC system, formulae can be derived to individual taxa and families.

(1) Engler and Diels (1936) included Canellaceae in the order Parietales. When NPC formulae of all the families included in the Parietales are observed, they appear to be more or less uniform but Canellaceae appears to be an exception. Subsequently Melchoir (1964) divided Partietales into two orders the Violales in which the NPC is essentially the Violales in which the NPC is essentially 345 throughout and others in Guttiferales.

(2) The eudicots are a large, monophyletic assemblage of angiosperms, comprising roughly 190,000 described species, or 75% of all angiosperms. The monophyly of eudicots is well supported from molecular data and supported by one palynological feature: a tricolpate or tricolpate-derived pollen grain. A tricolpate pollen grain has three apertures, equally spaced and approximately parallel to the polar axis of the grain. Apertures are differentiated regions of the pollen grain wall that may function as the site of pollen tube exit. Tricolpate pollen grains evolved from a monosulcate type (having a single aperture), which is considered to be ancestral in the angiosperms.

(3) The genus *Nelumbo* has till recently been included in Nymphaeaceae. Nelumbo has 3-colpate pollen while Nymphaeaceae have uniformly monosulcate pollen. Hence *Nelumbo* has been segregated into a separate family Nelumbonaceae.

(4) Bentham and Hooker (1862-1883) and other earlier taxonomists have included *Alisma, Butomus* and *Butomopsis* in the family Alismataceae. But Hutchinson (1969,

1973), Cronquist (1988) and Takhtajan (1980) have segregated *Alisma* into Alismataceae and *Butomus* and *Butomposis* into Butomaceae. This is supported on Palynological grounds. *Alisma* have pantoporate pollen while *Butomus* and *Butomopsis* have monocolpate one.

(5) *Caltha palustris* var. *palustris* and *C. palustris* var. *alba* can readily be distinguished by their aperture, as illustrated below.

	C. palustris var. *palustris*	*C. palustris* var. *alba*
Number of aperture:	Tricolpate	Pantoporate
Position of apertures:	Equatorial	Global
Size of apertures:	Large	Small

Exine sculpturing in taxonomic applications

The exposed surface-details of the pollen wall constitute the sculpturing. Some of the more important types are: Psilate (smooth), foveolate (pitted), fossulate (grooved), scabrate (very fine projections), verrucate (warty), baculate (rod-shaped with swollen tip) gemmate (sessile pillar), echinate (spiny), rugate (elongate elements irregularly distributed tangentially over the surface), striate (elongate, more or less parallelly distributed tangentially over the surface), punctate (minute perforations) and reticulate (elements forming open network).

Exine patterns have occasionally been found useful in differentiating species of the genus.

(1) In the genus *Bauhinia*, *B. racemosa* has reticulate, *B. purpurea* has reticulate-tuberculate, *B. malabarica* has spinulate *B. acuminata* has pilate, and *B. krugii* has striate pollen grains.

(2) The genus *Cicer* usually placed in the tribe Vicieae of the Fabaceae, has many characters, which suggested that this position is anomalous. Clarke and Kupicha (1976) studied the pollen grains of *Cicer*, of the Vicieae and the allied tribes, Trifolieae and Ononideae. They found that *Cicer* has pollen that is more similar to that of the Ononideae than that of Vicieae. They suggested the transfer of the genus *Cicer* from the Vicieae to the Ononideae.

(3) The two South American genera viz. *Abolboda* and *Orectantha* have been separated from Xyridaccae and kept under family Abolbodaceae. The pollen grains in Xyridaceae proper are smaller, aperturiferous with a thick exine without spinules. On

the other hand in Abolbodaceae the pollen grains are larger, spheroidal without any aperture and the exine is relatively thin and provided with spinules.

Pollen Size in taxonomic applications

(1) The genus *Theobroma* provides an example of a genus with two distinct types of pollen. One is small, flattened and is found in the majority of the species including *T. cacao*. The other type is larger, more elongate. This is one of the reasons for the recent removal of the species with larger pollen grains to a distinct genus *Herrania*.

Origin and evolution of angiosperms

Introduction

The subject of angiosperm origin is not yet a clearly settled issue in Botany. Still, there are several theories which speculate different ancestors to the angiosperms. As a matter of fact, Charles Darwin described the relatively rapid diversification of the higher plants (angiosperms) as an abominable mystery.

Time-line of origin as established by the earliest fossils

It is now widely accepted that the flowering plants originated in the early part of Cretaceous period.

The earliest definitive fossils of flowering plants are dispersed pollen grains from the earliest Cretaceous period, approximately 140 million years ago.

The earliest definitive flowers occur slightly later in the fossil record, about 130 million years ago. These early flowering plant fossils can largely be assigned to recognizable, extant groups.

Once angiosperms arose, they radiated apidly into several, distinct lineages and gradually replaced gymnosperms as the dominant plant life form on the earth.

Ancestors of angiosperms

Several workers have, from time to time, proposed the origin of angiosperms from the gymnosperms. However, the details of angiosperm evolution from a gymnosperm precursor are not clear.

Many angiosperm features, such as a reduced male gametophyte, reduced female gametophyte, and double fertilization with triploid endosperm, are microscopic and cytological and they are unlikely to be preserved in the fossil record.

Cladistic analyses of extant angiosperms have helped elucidate the features possessed by the common ancestor of the flowering plants.

Based on recent cladistic studies, *Amborella trichopoda* of the Amborellales is accepted as the most basal angiosperm lineage. Amborella lacks vessels and has unisexual flowers with a spiral perianth, laminar stamens, and separate carpels.

A current hypothesis on the origin of angiosperms is that they were derived by modification of some member of the group known as pteridosperms. The pteridosperms were among the earliest gymnosperms. They represent a paraphyletic assemblage of now extinct plants that possessed seeds and had generally fernlike foliage.

Caytonia as an ancestor

One fossil taxon of pteridosperms that exemplifies a possible transition to angiosperms is *Caytonia* of the Caytoniales. *Caytonia* possessed reproductive structures similar to those of the angiosperms.

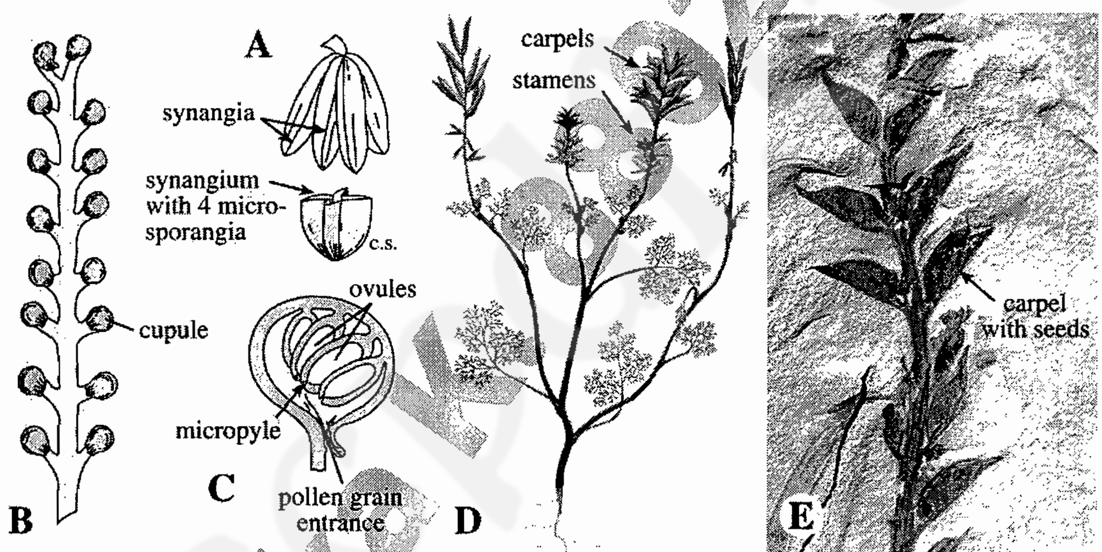


Figure 1: A–C. *Caytonia* A. Cluster of male reproductive units, each a radially symmetrical synangium of 4 microsporangia. (Cross section=c.s.) B. Reproductive axis, bearing two rows of cupules. C. Cupule, in sagittal section, showing four ovules and opening at base. D,E. *Archaefructus*. D. Reconstruction of *Archaefructus sinensis*, showing reproductive axis bearing stamens proximally and carpels distally. E. Fossil impression of carpel units of *Archaefructus lianogensis*.

The male reproductive structures resemble anthers in consisting of a fusion product (synangium) of three or four microsporangia; however, these differ from angiosperm anthers in being radially (not bilaterally) symmetric.

The female reproductive structures of *Caytonia* consist of a spikelike arrangement of units that have been termed cupules. Each cupule encloses a cluster of unitegmic ovules/seeds, with a small opening in the cupule near the proximal end. The cupule has been hypothesized

as being homologous with the angiosperm carpel. However, the cupule of *Caytonia* is different from what is presumed to be the ancestral carpel morphology, a conduplicate megasporophyll bearing ovules along two margins.

In addition, (monosulcate) pollen grains have been discovered at the micropyle of *Caytonia* ovules, evidence that the pollen grains were transported directly to the ovules, rather than to a stigmatic region where pollen tubes formed. Thus, the cupule apparently did not function as a carpel in terms of a site for pollen germination.

In summary, the homology of the reproductive structure in *Caytonia* is difficult to decipher, and no other pteridosperm is clearly an angiosperm progenitor.

However, some pteridosperms, like *Caytonia*, may still be more closely related to the angiosperms than to the other gymnosperms.

Importance of *Archaefructus* fossil

An example of a fossil that may help elucidate early angiosperm evolution is the genus *Archaefructus*, recently collected from China.

It is dated to a time of about 130 million years ago of the early Cretaceous.

Archaefructus (with two described species) was an aquatic plant, having dissected leaves and elongate reproductive axes, each of the latter with paired stamens below and several-seeded carpels above.

Although *Archaefructus* appears to have proper carpels, its relationship to extant angiosperms is debatable.

By one hypothesis, the reproductive axis is interpreted as an entire, perianth-less flower (with stamens below and carpels above), the axis perhaps homologous to an elongate receptacle reminiscent of some Magnoliaceae. By this interpretation, this reproductive structure might represent an ancestral flower (or flower precursor), and *Archaefructus* might be sister to the extant angiosperms.

An alternative hypothesis views the reproductive axis of *Archaefructus* not as a single flower, but as an inflorescence of individual, reduced male and female flowers, as seen in some aquatic angiosperms today. By this viewpoint, *Archaefructus* may represent an extinct off-shoot of an extant lineage within the angiosperms (such as the Nymphaeales).

Conclusion

In summary, it seems that more fossils may need to be discovered and described (or reinvestigated with new techniques) before the mystery of angiosperms origin can be satisfactorily solved. Cladistic analyses can help, but there is always the problem of homology assessment with structures that are very different from contemporary forms. Despite the fact that the relationships among extant flowering plants are much better known with advanced molecular techniques, fossils will be key to understanding their origin. Paleobotanical work should be continuously emphasized as of the utmost importance in understanding plant relationships.

Comparative account of various systems of classification of angiosperms

Introduction

Understanding diversity is a fundamental human activity. It is important for the build-up of knowledge. This has led to the recognition of the uses of different organisms by man since ancient times. As early as when he was a nomad and food gatherer, man tried to distinguish plants on the basis of their economic use i.e. edible plants, non-edible plants, medicinal plants, fuel plants etc. This was the first step in understanding plant diversity. It laid the foundation for the development of classification as a science.

There are a large number of plant species exhibiting tremendous variation in form, structure, mode of life and various other aspects. In order to effectively study this diversity, the plants are grouped into discrete units based on the overall similarities and differences. As knowledge developed, different criteria were used for classification. The earliest classifications of plants were based on their utility. This was followed by using the gross morphology of the plants. Thus, vegetative characters, floral characters and later on a large number on characters were used for classification. The floral characters were given greater significance as these are more stable and inherited. As modern botany advanced the criteria changed to include the evolutionary relationships among the different groups of plants also.

Classification thus aims to arrange plants in a systematic sequence based on their similarities and differences. The more the similarities, the more the plants are related. The closely related plants are grouped together and unrelated plants are kept in separate groups. Classification is thus the scientific practice of placing plants into groups and categories for a clear understanding, proper study and effective organization. In real terms, classification helps us in summarizing knowledge and to understand the objects/organisms we are analyzing. It is the knowledge of the plant structure/function which serves as the main criteria for classification.

Classification is a very basic science. It is based on logic/reason. This can be appreciated when we analyze the history of plant classification. This very interesting aspect helps us to understand how various taxonomists have significantly contributed towards the development and evolution of this interesting science.

Types of Classification

Several systems of classification have been proposed by taxonomists. These can be broadly grouped into three types:

1. Artificial Classifications: The earliest systems of classification were artificial since they were based on one or few easily observable characters. These classifications did not take into account the relationship between the plants classified. For example Theophrastus, emphasizing plant morphology, classified plants into four groups on the basis of their habit: herbs, undershrubs, shrubs and trees. Another example is of Carolus Linnaeus who classified plants on the basis of number of stamens and their cohesion, (the classification is referred as Sexual System of classification). These artificial systems were easy to use, because only a few characters had to be recognized. The classification was rigid. However, the major drawback of these classifications was that often totally unrelated plants were grouped together and those that were closely related, were placed in separate groups. These classifications would change whenever new information was incorporated into the system.

2. Natural Classifications: Natural classifications are based on a large number of characters. This enabled an understanding of the relationships amongst plants as they exist in nature. Initially, natural classifications were based mainly on morphological features and overall similarities using as many taxonomic characters as possible. This helped in placing the closely related taxa together or close to one another. The concept was initiated by Michael Adanson and extensively used by Bentham and Hooker. Natural classifications analyze the overall similarity for determining the relationship amongst the taxa. Thus, modern classifications are broad based, using data obtained from a number of branches such as morphology, anatomy, embryology, phytochemistry, ultrastructure etc. Hence, this is also referred as Phenetic relationship. Thus, natural systems of classification incorporate a wide range of information, so that plants similar in hierarchy can be grouped together and any further additional information can be included easily. Therefore, these classifications will not change whenever new information is incorporated into the system. Unlike the rigid artificial classifications, natural classifications are flexible.

3. Phylogenetic classifications: Charles Darwin's publication "Origin of Species" (1859) changed the outlook of the taxonomists. The most significant aspect of the theory of evolution was the concept that "species are not static entities". They are the products of evolution. This should be reflected in the systems of classification. Therefore, the later classifications were mostly based on the course of evolutionary descent. These tried to reflect the evolutionary sequence / relationship between different plant groups and were usually constructed on the basis of natural classification. Such classifications are recognized as phylogenetic because they are based on phylogeny/evolutionary history. The authors of these systems laid emphasis on certain pre-selected characters which they considered to be of phylogenetic importance. The evolutionary relationship is depicted through a diagram referred as phylogram or phylogenetic tree. The most widely known phylogenetic classifications include those of Engler and Prantl, Hutchinson, Takhtajan, Cronquist, Dahlgren and Thorne.

Natural Classifications are referred to as horizontal classifications as they are based on the overall data which is available during that particular time period. On the other hand, Phylogenetic Classifications are referred to as Vertical Classifications as they are based on evolutionary relationship or presumed ancestry.

Bentham and Hooker System of Classification

The most accepted natural system of classification of seed plants (Phanerogams) was jointly proposed by two British Botanists, George Bentham and Sir J.D. Hooker in three volumes of *Genera Plantarum* (1862 – 1883), published in Latin.

George Bentham was a self-trained and highly accomplished taxonomist. Sir Joseph Dalton Hooker was one of the greatest British botanists who explored many parts of the world. He was a close friend of Charles Darwin and founder of phytogeography (geographical botany). He succeeded his father as the Director Royal Botanic Garden, Kew (England), and held the post for almost twenty years. J. D. Hooker was the first European botanist to collect plants from the Himalayas.

Bentham and Hooker's system of classification included only the seed plants or Phanerogams. The system described and classified about 97,205 plant species into 202 families and 7569 genera based on their natural similarities. The classification was based on the form relationship and plant characters which could be correlated with each other. The system was based on the classification of A.P. de Candolle and Lindley.

It is one of the most popular systems of classification followed in many herbaria of the world even today. The classification was based on an actual study of the plant specimens and was not compiled from the work of the earlier authors. This made it a very accurate, authentic and popular classification. They provided key characters for the families and genera which was an easy aid for identification.

Outline

Phanerogams or seed plants

Class 1: Dicotyledons
(14 series,
25 orders and 165 families)

Subclass 1 : Polypetalae
Series 1: Thalamiflorae (6 orders)
Series 2: Disciflorae (4 orders)
Series 3: Calyciflorae (5 orders)

Subclass 2: Gamopetalae
Series 1: Inferae (3 orders)
Series 2: Heteromerae (3 orders)
Series 3: Bicarpellatae (4 orders)

Subclass 3: Monochlamydeae
Series 1: Curvembryeae
Series 2: Multiovulatae aquaticae
Series 3: Multiovulatae terretris
Series 4: Microembryeae
Series 5: Daphnales
Series 6: Achlamydosporae
Series 7: Unisexuales
Series 8: Ordines anomali.

Class 2 : Gymospermae
3 families

Class 3 Monocotyledons
(7 series, 34 families)

Series 1: Microspermae
Series 2: Epigynae
Series 3: Coronarieae
Series 4: Calycineae
Series 5: Nudiflorae
Series 6: Apocarpae
Series 7: Glumaceae

The seed plants or Phanerogams were divided into three classes – Class I: Dicotyledons, Class II: Gymnosperms and Class III: Monocotyledons. Each class is further divided into subclasses, each subclass into series, cohorts (modern orders) and orders (modern families).

Class I: Dicotyledons, characterized by reticulate venation and presence of two cotyledons in the seed, are divided into three subclasses – Polypetalae, Gamopetalae and Monochlamydeae, based on the nature of the perianth. This could have free (poly-) or fused (gamo-) petals, or it consisted of one (mono-) whorl only.

Subclass Polypetalae is characterized by having free petals. It was further subdivided into 3 series –

Series 1. Thalamiflorae: having hypogynous flowers with many stamens. The thalamus is elongated, conical or convex. It included 6 orders (and 34 families) starting with Ranales and ending with Malvales.

Series 2. Disciflorae: having hypogynous flowers with a cushion-like disc around or below the ovary. It included 4 orders (and 22 families) starting with Geraniales and ending with Sapindales.

Series 3. Calyciflorae: having epigynous or perigynous flowers; the thalamus is cup- shaped. It included 5 orders (and 27 families) starting with Rosales and ending with Umbellales.

Subclass Gamopetalae having a distinct calyx and corolla with fused petals. Based on the nature of ovary and the number of carpels and stamens, it was further subdivided into 3 series –

Series 1. Inferae: having an inferior ovary. It included 3 orders (and 9 families) starting with Rubiales and ending with Campanales.

Series 2. Heteromerae: having a superior ovary and more than two carpels. The stamens are generally more than (or equal to) the number of petals. It included 3 orders (and 12 families) starting with Ericales and ending with Ebenales.

Series 3. Bicarpellatae: having a superior ovary and usually two carpels. The stamens are generally equal to or less than the number of petals. It included 4 orders (and 23 families) starting with Gentianales and ending with Lamiales.

Subclass Monochlamydeae was based on single character i.e. perianth. It is present as a single whorl, or may be completely absent (thus the flowers become

naked). When present, it is not distinguishable into calyx and corolla, and can be either green (sepaloid) or brightly coloured (petaloid). It was subdivided into 8 series starting with Series Curvembryae and ending with Series Ordines Anomali. This has resulted in unnatural grouping of families. The orders which were disputed and could not be given a satisfactory position were placed in Ordines Anomali. The series are not divided into orders (cohorts) and are directly divided into 42 families.

Class 2: Gymnosperms are with naked seeds, divided into 3 families: Cycadaceae, Coniferaceae and Gnetaceae.

Class 3: Monocotyledons was characterized by having leaves with parallel venation, and a seed with a single cotyledon. It was subdivided into 7 series starting with Series Microspermae and ending with Series Glumaceae. The series were not divided into orders (cohorts) and are directly divided into 34 families.

Thus, the Monocotyledons, like the Subclass Monochlamydeae are divided into Series and Orders only; unlike the Subclasses Polypetalae & Gamopetalae (of the Class Dicotyledonae) which are divided into (i) Series, (ii) Cohorts, & (iii) Orders.

Merits of Bentham and Hooker System of Classification

1. It is a natural system of classification with immense practical utility. It is very popular in many countries and used for arrangement of plant species in Kew Herbarium, and in many countries including India.
2. The descriptions of the taxa are based on an actual study, thus making the system detailed, authentic and highly practical. The accuracy of Latin descriptions is unparalleled.
3. The larger genera are divided into subgenera with definite number of species which helps in easy identification of plants.
4. The keys for the identification of genera and families are precise and useful.
5. It includes geographical distribution of genera and species.
6. Dicots start with Ranales which is considered as most primitive amongst the angiosperms by many taxonomists.
7. The gymnosperms are placed as a separate independent group and not along with dicots as had been done by de Candolle.
8. The monocots are placed after dicots which is accepted by present day taxonomists.
9. The position of gamopetalae after polypetalae is accepted as fused petals are considered an advanced character over free petals.
10. The sequence adopted in the classification suggests an evolutionary pattern.

Demerits of Bentham and Hooker System of Classification

1. The classification does not include any information about the origin of angiosperms even when it was published after Darwin theory of evolution.
2. The position of gymnosperms between dicots and monocots is inappropriate according to the accepted evolutionary sequence. The gymnosperms constitute an independent group considered as equivalent to the angiosperms and are placed before them in most classifications.
3. The grouping of Monochlamydeae is artificial as it is based on single character and has separated some closely related families. For example:
   A. Chenopodiaceae, Illecebraceae (placed in Monochlamydeae) are related to Caryophyllaceae (placed in Polypetalae), and placed in same order by modern taxonomists.
   B. Podestemaceae (belonging to Multiovulatae aquaticae, Monochlamydeae) is regarded closely related to Saxifragaceae or Crassulaceae of Rosales (placed in Polypetalae).
   C. Lauraceae (belonging to Daphnales, Monochlamydeae) is considered related to Magnoliaceae of Ranales (belonging to Polypetalae).
   D. Nepenthacaeae (belonging to Multiovulatae terrestris, Monochlamydeae) is related to Saracenniaceae (placed in Parietales, Polypetalae).
4. Advanced family like Orchidaceae with inferior ovary and zygomorphic flowers has been considered primitive by placing it in the beginning of Monocots.
5. The arrangement of Monocots is unnatural and un-phylogenetic.
6. Compositae or Asteraceae has been placed in the beginning of Gamopetalae which is unnatural.
7. Families Liliaceae (placed in Coronarieae) and Amaryllidaceae (placed in Epigynae) are closely related but have been separated on the basis of ovary characteristics.
8. The position of Series Inferae with inferior ovary before the series Heteromerae and Bicarpellatae with superior ovaries, is not accepted as the inferior ovary is derived from the superior ovary.

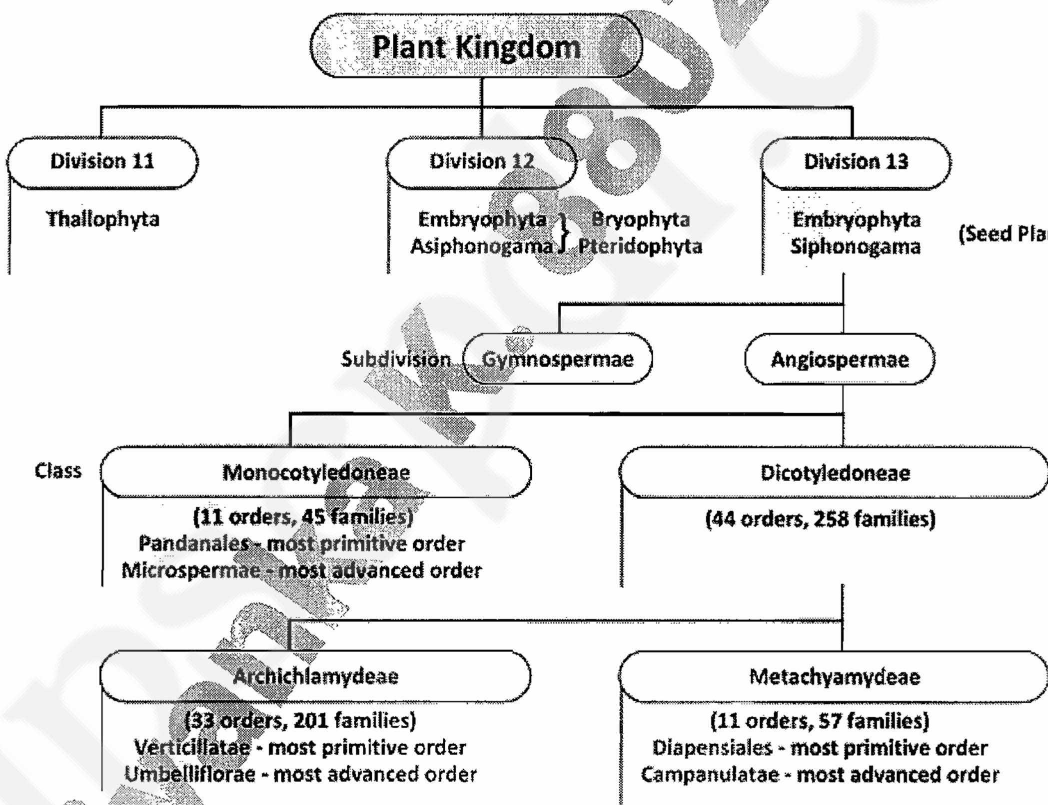
Engler and Prantl System of Classification

Heinrich Gustav Adolph Engler (1844 – 1930) and Karl A E Prantl (1849 – 1893)

The two German botanists published a phylogenetic classification in 23 volumes (1887 – 1899) of *Die naturlichen Pflanzenfamilien* (= The Natural Plant Families). This illustrated work provided phylogenetic arrangement, description and keys for identification of all the

plant families from the primitive algae to advanced seed plants known at that time. It included description up to the genus level. Engler and Prantl classified all the plants from algae to angiosperms. In this system, the plant kingdom was divided into 13 Divisions in an evolutionary sequence. The 13th Division, *"Embryophyta Siphonogama"*, classified the angiosperms. A summary of the original work was published and subsequently revised by many botanists as *Syllabus der Pflanzenfamilien* and published in several editions. The system now recognizes 17 Divisions in plant classifications. The last (12th edition) of *Syllabus der Pflanzenfamilien* was published by Melchoir (1964). Engler also published taxonomic monographs of various families (up to species entitled) *Das Pflanzenreich*. The classification is based on Eichler's system with modifications. This system is still used in many American and European herbaria.

Outline



The classification covered the entire plant kingdom from algae to angiosperms which has been divided into 13 divisions. The first 11 divisions are Thallophytes, 12th division is Embryophyta Asiphonogama (plants with embryos but no pollen tubes; Bryophytes and Pteridophytes) and the 13th division is Embryophyta Siphonogama (plants with embryos and

pollen tubes) which includes seed plants. This is divided into 2 subdivisions: 1. Gymnospermae, 2. Angiospermae.

The subdivision Angiospermae is further divided into 2 classes:

Class 1. Monocotyledoneae

Class 2. Dicotyledoneae

Class 1. Monocotyledoneae include 11 orders starting with order Pandanales with naked unisexual flowers and ending with order Microspermae with family Orchidaceae. Orchidaceae is considered as the most advanced family and evolved over grasses.

Class 2. Dicotyledoneae is divided into 2 subclasses: Subclass 1. Archichlamydeae and Sublass 2. Sympetalae or Metachlamydeae. Archichlamydeae include 33 orders starting with order Verticillatae and ending with order Umbelliflorae. It included achlamydeous or monochlamydeous families at the beginning and dichlamydeous and polypetalous families in the end. Hence, Archichlamydeae comprised of the Poylpetalae and Monochlamydeae of Bentham and Hooker's classification. Sympetalae included Gamopetalous flowers with 11 orders starting with order Diapensiales and ending with order Campanulatae.

Merits of Engler and Prantl System of Classification

1. The classification incorporated evolution and was the beginning of phylogenetic classifications.
2. The system classified all the plant families from the algae to angiosperms.
3. Gymnosperms were considered primitive and placed before angiosperms.
4. The taxa were fully illustrated, described along with identification keys upto family level in *Syllabus der Pflanzenfamilien*, up to genus level in *Die naturlichen Pflanzenfamilien* and for many families along with their species in *Das Pflanzenreich*.
5. The description of families also contained information on embryology, anatomy and geographical distribution.
6. The classification was very elaborate, extensive and is still followed in many herbaria and floras of the world.
7. The polypetalous condition was considered primitive than gamopetalous condition which is also the present phylogenetic view.
8. The Polypetalae and Monochlamydeae of Bentham and Hooker's classification were merged into a single subclass Archichlaymdeae which resulted in proper placement

of many families. For example family Illecebraceae is combined with family Caryophyllaceae. Families Amaranthaceae, Chenopodiaceae and Caryophyllaceae are included in the same order Centrospermae.

9. Families Compositae and Orchidaceae in dicots and monocots respectively are considered advanced are placed at the end of each group.

Demerits of Engler and Prantl System of Classification

1. The classification though not intentionally was more natural and less phylogenetic.
2. The classification equated simplicity of structure with primitiveness and did not recognize the simplicity due to evolutionary reduction. Thus the classification was not phylogenetic in true sense.
3. Monocotyledons were placed before dicots but this placement was reversed in the 1964 edition of *Syllabus der Pflanzenfamilien*.
4. The naked flowers of Amentiferous families were considered primitive, but evidences from floral anatomy, wood anatomy and palynology suggest these are not primitive but simple due to the disappearance of perianth and evolutionary reduction.
5. Unisexual flowers were treated as primitive, but evidence from floral anatomy has shown that the unisexual condition is derived from bisexual condition by suppression of either androecium or gynoecium.
6. Monochlamydeous flowers (one whorl of perianth) were treated primitive over dichlamydeous flowers (distinct calyx and corolla) which is not accepted by modern taxonomists.
7. Angiosperms were considered to be polyphyletic in origin, but modern taxonomists regard angiosperm to be monophyletic in origin.
8. Ranales are considered primitive by modern taxonomists, but they have been placed after Centrospermae at a position not accepted by modern taxonomists.
9. Araceae in Monocotyledons are derived from Liliaceae, but Araceae have been placed before Liliaceae, a position not accepted by modern taxonomists.
10. Helobieae consisting of primitive groups have been placed between two advanced orders Pandanales and Glumiflorae.

Takhtajan System of Classification

Armen Takhtajan (1919 – 2009) proposed a phylogenetic system of classification. He was a Russian taxonomist who worked at the Komarov Botanical Institute in Leningrad, now named St. Petersburg.

He published his classification in 1954 in Russian which was translated in English as "The Origin of Angiospermous Plants" (1958). The classification was modified and detailed in Russian books *Die evolution der angiospermen* published in 1959 and *Systema et phylogenia magnoliophytorum* in 1966.

The system of classification was further revised in the *Botanical Review* (1980).

The final classification was published in book entitled *Diversity and Classification of Flowering Plants* (1997).

Outline

Takhtajan's classification (1997) divided the Angiosperms (Division Magnoliophyta) into two classes Magnoliopsida (Dicotyledons) and Liliopsida (Monocotyledons). Magnoliopsida is further sub-divided into 7 subclasses, 20 superorders, 71 orders and 342 families. Liliopsida is further sub-divided into 3 subclasses, 8 superorders, 21 orders and 77 families. The order Magnioliales is the most primitive order which gave rise of all branches of Angiosperms.

The following is an outline of Takhtajan system of classification.

Division Magnoliophyta

2 classes, 17 subclasses, 71 superorders, 232 orders, 589 families (1997)

Class I Magnoliopsida

11 subclasses, 55 superorders, 175 orders, 458 families (1997)

Subclass

1. Magnoliidae
2. Nymphaeidae
3. Nelumbonidae
4. Ranunculidae
5. Caryophyllidae
6. Hamamelididae
7. Dilleniidae
8. Rosidae
9. Cornidae
10. Asteridae
11. Lamiidae

Class II Liliopsida

6 subclasses, 16 superorders, 57 orders, 131 families (1997)

Subclass

1. Liliidae
2. Commelinidae
3. Arecidae
4. Alismatidae
5. Triurididae
6. Aridae

Takhtajan considered a number of criteria in deciding the relative degree of advancement in flowering plants which are:

1. Woody plants are primitive than the herbaceous ones. Primitive angiosperms were smaller woody forms which evolved into larger tropical trees and deciduous trees.
2. Simple leaves having entire margin with pinnate venation are primitive, which evolved into palmately lobed and compound leaves.
3. Pinnate venation is primitive to palmate venation, and parallel venation is most advanced.
4. Alternate leaf arrangement is primitive and gave rise to opposite and whorled arrangement.
5. Stomata with subsidiary cells are primitive and ones without subsidiary cells are advanced.
6. The solitary and terminal flowers are primitive. Cymose inflorescence is more primitive and racemose advanced.
7. Flowers with moderately elongated floral axis with indefinite and variable number of floral parts are primitive. During floral evolution there was a shortening of floral axis and gradual change to finite number of floral parts with cyclic arrangement.
8. Primitive stamens were leaf-like microsporophylls with microsporangia (not differentiated into filament and connective), which evolved into the advanced stamens differentiated into filaments, anthers and connectives. These have either the abaxial type (extrose) or the adaxial type (introse) of anther dehiscence.
9. Monocolpate pollen grains are primitive which evolved into tricolpate pollen grains.
10. Pollen (exines) without external sculptures are primitive and those with various types of sculptures are advanced.
11. Primitive carpels are free having many ovules and laminar placentation. The union of carpels led to the syncarpous condition.
12. Bitegmic ovules are primitive and unitegmic ovules arose from bitegmic ovules by the union of two integuments or abortion of one.
13. Anatropous ovule is primitive basic type from which different ovules are derived.

14. Primitive type of female gametophyte is monosporic eight nucleate (Polygonum type) from which different types are derived. Tetrasporic type of female gametophyte is most advanced.
15. Porogamy is primitive condition and mesogamy and chalozogamy are advanced conditions.
16. Primitive seed is of medium size from which small and large seeds are derived. Primitive seeds had abundant endosperm with minute and undifferentiated embryo, while the advanced seed had reduced endosperm and large and well developed embryo. The monocot embryo is derived from the dicot embryo.
17. Many seeded follicle from multicarpellate, apocarpous gynoecium is primitive basic type from which other types of fruits are derived.

Merits of Takhtajan System of Classification

1. The classification is phylogenetic as it is based on well established phylogenetic principles.
2. The nomenclature of various groups is in according to the rules of International Code of Botanical Nomenclature.
3. The earlier grouping of the angiosperms (Polypetalae, Gamopetalae and Monochlamydeae of Bentham and Hooker as well as Archichlamydeae and Metachlamydeae of Engler and Prantl) has been replaced with definite "subclasses". Thus, the division of the dicotyledons (Magnoliopsida) and monocotyledons (Liliopsida) into defined "subclasses" has been considered a 'major advancement' in understanding the phylogeny of the angiosperms (Magnoliophyta). The introduction of the rank of "super order" in the classification has provided an important link between the large 'subclass' and the smaller 'order".
4. The system follows a natural assemblage of families, based on a synthesis of information obtained from various disciplines. Thus, families Lamiaceae and Verbenaceae are positioned together in the order Lamiales; Caryophyllaceae, Chenopodiaceae and Portulacaceae are put together in the order Caryophyllales.
5. Dicots begin with Magnoliales as the most primitive angiosperm is universally accepted.
6. The position of Magnoliales at the start of Magnoliopsida is in accordance with evolutionary progression.

7. Monocots are derived from an extinct hypothetical terrestrial group of Magnoliidae and Nymphaeales and Alismatales are lateral side branches is also accepted fact.
8. The concept of primitive flower in the classification is in accordance with modern taxonomists.
9. Bubble diagram showing relationships between different groups, subclasses and superorders is helpful in indicating the relative size of different groups along with the advancement.

Demerits of Takhtajan System of Classification

1. The taxa are too narrowly defined which has resulted in the unwanted splitting of related taxa. For example Papaveraceae is separated from order Capparales.
2. The classification is only till the family level and key for identification are also not given. Hence the classification is not useful for practical identification.
3. Few of the phyletic principles given by him are not accepted by present day taxonomists.
4. Takhatajan considers Degeneriaceae as the most primitive angiosperm but many present day taxonomists consider Winteraceae to be most primitive family in angiosperms.
5. The classification incorporates data from a number of branches but greater emphasis is given to cladistic information than phenetic information.

Angiosperm Phylogeny Group (APG)

Angiosperm Phylogeny Group (APG) refers to an informal collaboration of an international group of taxonomists who have collectively proposed a phylogenetic classification reflecting plant relationships. Their aim was to provide a stable reference for angiosperm classification.

The members of the APG include B. Bremer, K. Bremer, M. W. Chase, P. F. Stevens, W. S. Judd, A. Bucklund, B. Briggs, M. H. G. Gustafsson, F. A. Kellogg, M. Thulin and many more contributors. The classification was first published in 1998, referred as the APG System. Since then it has been revised twice in 2003 (called as APG II) and in 2009 (called as APG III). Many members of APG and independent researchers also publish their findings and research on the angiosperm taxonomy and phylogeny. P. F. Stevens who is the contributor for all APG versions maintains a website called AP-web, which is hosted by Missouri Botanical Garden since 2001 and it is an important source for angiosperm phylogeny research.

The APG system is based on cladistic analysis of the DNA sequences of three genes, two chloroplast genes and one gene coding for ribosomes. Even though it is based on molecular evidences the constituent groups are also supported by other evidences such as morphology. This system classifies the angiosperms as a subclass Magnoliidae under class Pinnatae (seed plants). They have considered angiosperm group to be monophyletic in origin (i.e. all descendents have a common ancestor). They did not recognize the traditional Dicotyledons and Monocotyledons as this would make the group paraphyletic (i.e. one ancestor but all its descendents are not in one group). Formal scientific names above the level of order have not been used i.e. an order is the highest rank with a formal botanical name. Higher groups are defined only as clades with names such as eudicots, monocots, rosids, asterids etc. The APG system (1998) classified 462 families which were placed in 40 monophyletic orders under informal monophyletic higher groups: Monocots, Commelinoids, Eudicots, Core Eudicots, Rosids, Eurosids I, Eurosids II, Asterids, Euasterids I and Euasterids II. In the beginning there were 11 unclassified families and 4 orders without any supraordinal grouping or in a further clade. At the end there were 25 families of uncertain position.

The APG II System published in2003 documented 45 orders and 457 families along with 39 families which were not placed under any order. The APG III System published in2009 recognized 14 new orders along with the existing 45 orders and 413 families along with 10 families not placed under any order.

The APG classification is becoming progressively more popular and regarded as an authoritative point of reference. Many herbaria of the world including Kew Botanical Garden have changed their order of collection in according to the APG classification

Conclusion

Classification is the grouping of taxa or plants on the basis of their similarities. Various botanists have formulated different methods of classification from time to time.

The science of classification is a dynamic field. Recent developments in DNA technology and genetic analysis have shown new ways for interpreting facts. The genetic information is now being used to analyze the similarities and relationships among organisms. The classification of species and plants continue with the traditional morphological ways along with the light of new information. The systems of classification will continue to evolve and go a long way with taxonomists integrating and reinterpreting facts.

evolution

BOTANY REFERENCE NOTES

Paper – I

Angiosperm Systematics: Part – II

An account of different angiosperm families

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Contents

1. Magnoliaceae

Magnolia family

7 genera, 182 species

Warm temperate to tropical regions of Southeast, North and Central America, West Indies, Brazil, and East Asia.

Salient features: Trees or shrubs with alternate simple leaves, stipules caducous, leaving a circular scar at the node, nodes multilacunar, flowers usually solitary, bisexual, large, floral parts numerous, spirally arranged on elongated thalamus, tepals gradually passing from outer sepals to inner petals, stamens laminar, carpels free, seed often suspended by thread like funiculus.

Major genera: *Magnolia* (80 species), *Michelia* (40), *Talauma* (40) *and Liriodendron* (2).

Description: Trees or shrubs, nodes 5-lacunar or multilacunar, vessels-elements with scalariform ends, vessels without vestured pits, wood parenchyma apotracheal (terminal), sieve-tube plastids S-type, or Ptype and S-type; when P-type, subtype I (b). **Leaves** evergreen or deciduous, alternate, spiral, petiolate, simple, dissected (Lirio-dendron), pinnatifid or entire, pinnately veined, or palmately veined, stipules large, sheathing, enclosing the terminal buds, caducous, leaving a ring-shaped scar at the node, stomata paracytic, or anomocytic, minor leaf veins without phloem transfer cells (Magnolia). **Inflorescence** with usually solitary terminal, or axillary flowers. **Flowers** bracteate (the bracts spathaceous); large, regular, bisexual. **Perianth** with 6-18 tepals, free, sequentially intergrading from sepals to petals, or petal-like (usually), usually spirally arranged, rarely 3–4 whorled, white, or cream, or pink, deciduous. **Androecium** with numerous (50–200) stamens, maturing centripetally, free, spirally arranged, all fertile, usually laminar (the four paired microsporangia embedded, the stamens often more or less strap-shaped), anthers adnate, dehiscence longitudinal, through slits or valves, extrorse (Liriodendron), or latrorse to introrse, bithecous, appendaged often by prolongation of the connective or unappendaged, pollen grains monosulcate. Gynoecium with (2–) 20–200 free carpels, ovary superior, carpel fully or incompletely closed, 2 (–20) ovuled, placentation marginal; ovules funicled, pendulous, biseriate (on the ventral suture), anatropous, bitegmic, crassinucellate; stigma extending down the style, but sometimes terminal. Fruit an aggregation of follicles or indehiscent samaras (Liriodendron), or united into fleshy syncarp (Aromadendron); seeds endospermic, endosperm oily, seeds usually large, often with long thread-like funiculus. Pollination primarily by beetles. The fruits are primarily dispersed by animals, but the samaras of Liriodendron are wind dispersed.

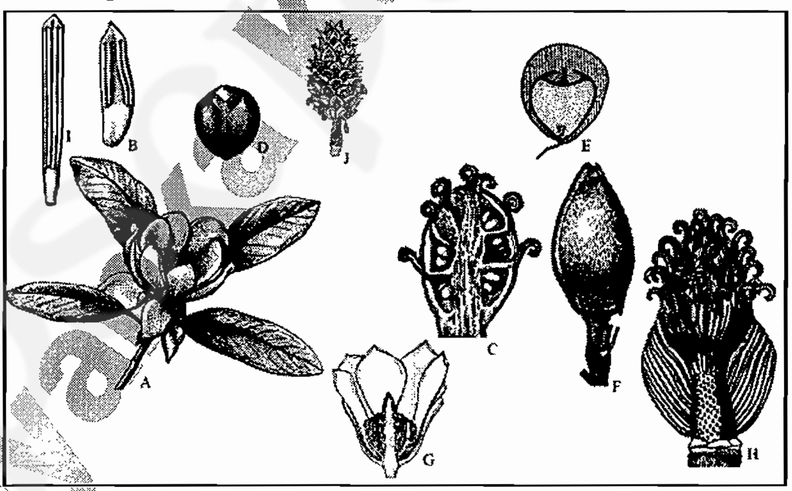

Figure-1: Magnoliaceae. *Magnolia virginiana*. **A:** Flowering branch with single terminal flower; **B:** Stamen, laminar and with apical sterile appendage; **C:** Longitudinal section of gynoecium, two anatropous ovules in each carpel; **D:** Seed with fleshy seed coat removed; **E:** Longitudinal section of seed showing fleshy seed coat, copious endosperm and small embryo. *M. grandiflora*. **F:** Flower bud; **G:** Vertical section of flower; **H:** Floral receptacle with half of the stamens removed; **I:** Anther; **J:** Dehisced fruit with arillate seeds hanging through thread-like funiculus.

Economic importance: Various species of *Magnolia (M. grandiflora, M. kobus, M. stellata) and Michelia (M. fuscata, M. champacasapu*, also source of timber) are grown as ornamentals. Liriodendron tulipifera (tulip tree or yellow poplar) is a valuable timber source in USA. Species of *Magnolia (M. hypoleuca)*, and *Michelia* also constitute sources of timber.

Phylogeny: The family was regarded as the most primitive of the extant angiosperms for several decades in the classification systems of Hallier (1905), Hutchinson (1926, 1973), and earlier versions of Cronquist and Takhtajan. The view was first challenged by Smith (1945), who considered that Magnoliaceae are relatively highly specialized both vegetatively and florally, casting some doubt on the assumption of the primitive nature of the family, and implying that groups such as Winteraceae, etc., may be at least as primitive. The status of Magnoliaceae as the most primitive family was strongly challenged by Carlquist (1969), Gottsberger (1974) and Thorne (1976), claiming Winteraceae to be the most primitive family. The primitive features of Magnoliaceae include spirally arranged floral parts, laminar stamens, fruit a follicle, longer and narrower vessel elements, monosulcate pollen grains and beetle pollination.

The family is considered to be monophyletic based on the support from rbcL and ndhF sequences (Qui et al., 1993, Kim et al., 2001). These studies, however, question the recognition of *Talauma, Michelia and Manglietia* as distinct genera, as it renders Magnolia as paraphyletic. Although Liriodendron is quite distinct, all other genera have been merged with Magnolia in the recent works. Figlar and Nootebroom (2004) divide the enlarged genus Magnolia into three subgenera: Magnolia, Yulania and Gynopodium. Two clades are distinguished within the family one represented by Liriodendron, and the other by rest of the *genera. Judd et al., (2008), Stevens (2008) as such recognize only 2 genera Magnolia and* Liriodendron within the family. Thorne (2003, 2006, 2007), places Magnolia and other 5 genera in subfamily Magnolioideae, whereas *Liriodendron* is placed in monogeneric Liriodendroideae.

2. Ranunculaceae

Buttercup or Crowfoot family

58 genera, 2,505 species

Primarily in temperate and boreal regions of the Northern Hemisphere.

Figure-1 : Ranunculaceae. *Ranunculus muricatus.* **A:** A portion of plant with flowers and fruits; **B:** Vertical section of flower; **C:** Petal with nectary; D: Stamen; **E:** Achene. *Consolida ajacis.* **F:** A branch with young inflorescence and an expanded inflorescence; **G:** Vertical section of flower; **H:** Stamen; **I:** Dehiscing follicle. (A-E, after Sharma and Kachroo, Fl. Jammu, 1983).

Salient features: Herbs, leaves with sheathing base, blade often divided, flowers bisexual, petals with nectary, stamens and carpels numerous, free and spirally arranged, ovary superior, fruit a follicle or achene.

Major genera: *Ranunculus (400 species), Clematis (200), Delphinium (250), Aconitum (245), Anemone (150) and Thalictrum (100).*

Description: Mostly herbs, sometimes woody climbers (*Clematis*), or shrubs (*Xanthorhiza*). Stem with scattered or several rings of vascular bundles. Hairs simple. **Leaves** usually alternate (*opposite in Clematis*), undivided (*Caltha)* palmately lobed (*Ranunculus*) or compound (*Clematis*), stipules absent (*present in Thalictrum*). Tendrils for support may sometimes be formed from petiole (*Clematis*) or terminal leaflet (*Naravelia*). **Inflorescence** of solitary flowers (*Anemone*) or cymose, sometimes racemes (*Delphinium*) or panicles (*Clematis natans*). **Flowers** bracteate (*Clematis*) or ebracteate (*Anemone*) bisexual (*unisexual in Thalictrum*), actinomorphic (*zygomorphic in Delphinium*) with spirally arranged stamens and carpels, hypogynous. **Calyx** with 5 (4 in Clematis) or many sepals, free, one (*Delphinium*) or all five (Aquilegia) sepals often produced into spur at base. Corolla with 5 or many (*Helleborus*) petals, free, often with nectaries or represented only by nectaries (*Delphinium*), sometimes produced into spur which enters the spur formed by sepal, sometimes perianth is not differentiated (Anemone, Helleborus) into sepals and petals. **Androecium** with many stamens, free, spirally arranged anthers often extrorse, dehiscence longitudinal. **Gynoecium** with single (Consolida) or many free (Delphinium) carpels (syncarpous in Nigella), unilocular (*multilocular in Nigella*) with single (Ranunculus) or many (Delphinium) ovules, placentation marginal or basal, rarely axile (Nigella), ovary superior, style 1, sometimes feathery (*Clematis*), stigma 1. **Fruit** an achene (Ranunculus), follicle (Delphinium), berry (Actaea) or rarely a capsule (Nigella); seed with small embryo, endosperm present. Pollination usually by insects. Clematis and Anemone, which lack nectaries are pollinated by pollen-gathering insects. Ranunculus, Delphinium, etc., with nectarines by usually bees. Some species of Thalictrum are wind pollinated. Achenes may be provided with hairs for wind dispersal (Clematis), with tubercles or hooked spines for dispersal by animals (Ranunculus). Berries of Actaea are mainly dispersed by birds.

Economic importance: *Delphinium* (Larkspur), *Anemone* (windflower), *Aquilegia* (columbine), *Ranunculus* (buttercup), and *Helleborus* (hellebore) are grown as ornamentals. Aconitum napellus yields aconite, whereas A. ferox is source of bikh poison. Roots of Hydrastis (removed by Takhtajan to Hydrastidaceae) are used for stomach ailments. Seeds of Nigella sativa (*Nigella, black seed, 'Kalonji'*) are used as flavouring, medicinally to treat asthma, bronchitis and rheumatism. Thymoquinone extracted from the seeds of this species have recently been found to be useful in treatment of cancer.

Phylogeny: The family is largely considered to be a monophyletic group as supported by morphology and molecular evidence. Hydrastis, with 3-merous perianth, vessels with scalariform perforations, ovule with two integuments, and fleshy follicles occupies a unique basal position along with Glaucidium, as evidenced by molecular data. Both these genera were removed by Takhtajan (1997) into distinct families Hydrastidaceae and Glaucidiaceae, under Hydrastidales and Glaucidiales, respectively. Thorne (2003) includes Glaucidiaceae under Paeoniales, but Hydrastidaceae near Ranunculaceae under Ranunculales. Studies based on cpDNA restriction sites and sequence data (Hoot, 1995) suggest that these two genera along with other genera placed in Thalictroideae form basal paraphyletic group, thus justifying retaining all these genera within Ranunculaceae. These basal genera retain plesiomorphies such as presence of berberine, yellow creeping rhizomes, small hairs and small chromosomes, linking them to Berberidaceae. The separation of follicle bearing genera under Helleboraceae by Hutchinson is rejected by the evidence from floral anatomy. The reduction in the number of ovules per carpel and the evolution of achenes has occurred several times within the family. The separation is also negated by nucleotide sequences (Hoot, 1995). The petals with nectary are often considered to represent petaliferous nectaries, the petals being absent. According to Erbar et al., (1999) they are interpreted as being derived from stamens, and that stamens are secondarily spiral. Thorne (2003, 2006) divides family Ranunculaceae into 3 subfamilies: Coptidoideae, Isopyroideae (Thalictroideae in 2007 revision) and Ranunculoideae. Stevens (APweb, 2006) recognizes 5, adding Hydrastidoideae and Glaucidioideae.

3. Brassicaceae

Mustard family

(=**Cruciferae** A. L. de Jussieu)

340 genera, 3,350 species

A cosmopolitan family mainly distributed in North Temperate Zone, particularly the Mediterranean region.

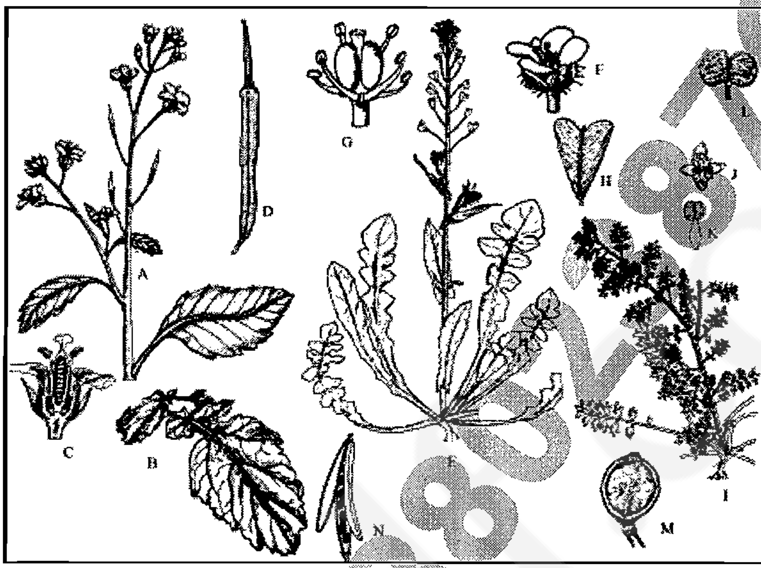

Figure-1: Brassicaceae. *Brassica campestris.* **A**: Upper part of plant with inflorescence; **B**: Lower leaf; **C**: Vertical section of flower; **D**: Siliqua with persistent style forming a long beak. *Capsella bursa-pastoris.* **E**: Plant with inflorescence; **F**: Flower; **G**: Flower with sepals and petals removed; **H**: Silicula with apical notch having persistent style, fruit flattened at right angles to the septum and as such replum appearing as vertical rim. *Coronopus didymus.* **I**: Plant with highly dissected leaves and axillary racemes; **J**: Flower from above showing minute petals and 2 stamens; **K**: Stamen; **L**: Silicula, deeply bilobed and prominent replum. **M**: Silicula of Lobularia maritime flattened parallel to the false septum and as such replum forming a ring around the fruit. **N**: Siliqua of Brassica nigra dehisced with valves separating and seeds attached to false septum.

Salient features: Herbs, sap watery, sepals and petals 4 each, free, stamens tetradynamous, ovary with false septum and a thickened placental rim called replum, ovary superior, placentation parietal, fruit a siliqua or silicula.

Major Genera: *Draba* (350 species), *Erysimum* (180), *Lepidium* (170), *Cardamine* (160), *Arabis* (160), *Alyssum* (150), *Sisymbrium* (90) *and Brassica* (50).

Description. Annual, biennial or perennial herbs (rarely undershrubs: *Farsetia*) with watery sap, containing glucosinolates (mustard oils) and with myrosin cells. Hairs simple, branched, stellate or peltate. **Leaves** alternate or in basal rosettes, simple, often dissected, rarely pinnate compound (Nasturtium officinale) sometimes bearing bulbils in axil (Dentaria bulbifera) or leaf surface (*Cardamine pratensis*), stipules absent. **Inflorescence** typically racemose, corymbose raceme, or flat topped corymb (Iberis), Cardamine also produces subterranean cleistogamous flowers. **Flowers** ebracteate, rarely bracteate (*Nasturtium montanum*), bisexual, actinomorphic or rarely zygomorphic (*Iberis*), hypogynous (perigynous in Lepidium). **Calyx** with 4 sepals, free, in two whorls, sepals of lateral pair sometimes saccate at base, green or slightly petaloid. **Corolla** with 4 petals, cruciform (arranged in a cross), clawed, sometimes absent in Coronopus and Lepidium. **Androecium** with 6 stamens (2 in Coronopus, 4 in Cardamine hirsuta, 16 in Megacarpaea), free, tetradynamous (*2 short 4 long*), dehiscence longitudinal, nectarines often present near base of stamens, pollen grains tricolporate or tricolpate. **Gynoecium** with two united (thus pistil single) carpels (syncarpous), rarely carpels 3 (*Lepidium*) or 4 (*Tetrapoma*), unilocular but becoming bilocular due to false septum that is surrounded by a thick placental rim called replum, ovules many, rarely single ovules, placentation parietal, ovary superior, gynophore distinct, style 1, stigmas 2. **Fruit** a siliqua (long: length thrice width or more) or silicula (short: length less than thrice width), at dehiscence valves break away from below upward leaving seeds appressed to false septum, fruit moniliform lomentum on Raphanus; seed

with large embryo, endosperm scant or absent. Pollination by insects, failure of cross pollination may result in self pollination. Seeds are usually dispersed by wind.

Economic importance: The family contributes a number of food plants such as radish (*Raphanus sativus*), cabbage (*Brassica oleracea var. capitata*), cauliflower (*B. oleracea var. botrytis*), Brussels sprouts (*B. oleracea var. gemmifera*), kohlrabi (*B. oleracea var. caulorapa*) and turnip (*B. rapa*). Seeds of B. campestris yield cooking oil those of black mustard (*B. nigra*) are used as condiment. Woad was formerly used a blue dye obtained from leaves of Isatis tinctoria. Common ornamentals include stock (*Mathiola*), candy tuft (*Iberis amara*), alyssum (*Alyssum*), wall flower (*Erysimum*) and sweet alyssum (*Lobularia*).

Phylogeny: The family is regarded as monophyletic, supported by evidence from morphology (gynophore, exserted stamens), glucosinolates, dilated cisternae in endoplasmic reticulum and rbcL sequences. The order Brassicales (others prefer Capparales) had long been treated as a well defined group, with Brassicaceae and Capparaceae considered to be fairly close as suggested by evidence from morphology, dilated cisternae, but have been treated as distinct largely because of several stamens and very long gynophore in Capparaceae.

Judd et al., (1994) on the basis of morphological studies, and Rodman et al., (1993) on the basis rbcL sequences, concluded that out of the traditional Capparaceae, Capparoideae and Cleomoideae do not form a monophyletic group, as also concluded earlier by Hutchinson (1973). Capparoideae according to these authors form basal paraphyletic group within Brassicaceae. Cleomoideae and Brassicoideae (traditional Brassicaceae) form monophyletic group based on synapomorphies of herbaceous character, replum in fruit and rbcL sequences. The merger of Capparaceae with Brassicaceae avoids arbitrarily delimited paraphyletic taxa, and thus forms monophyletic group with broadened circumscription. The two have been merged in APG-II and APweb classifications. APweb recognizes 3 subfamilies under broadly circumscribed Brassicaceae: Capparoideae, Cleomoideae and Brassicoideae. It is pertinent to note that Thorne (1999), who has been updating his classification in light of recent advances, has preferred to retain Brassicaceae and Capparaceae as distinct families, also separating Cleomaceae in recent revisions (2003, 2007), thus recognizing three subfamilies as independent families. According to the recent studies of Soltis et al., (2000) and Hall et al., (2002), Brassicaceae (Brassicoideae) and Cleomaceae (Cleomoideae) are more closely related and form a monophyletic group based on synapomorphies of herbaceous habit, rbcL sequences and presence of replum. It is interesting to record that although Hutchinson had indicated heterogeneity within Capparaceae, and reasoned that Cleome and its relatives were much closer to Brassicaceae, he had placed Capparaceae and Brassicaceae in two distinct orders Capparales (in his diagram he used name Capparidales) and Brassicales, even further separating them under Lignosae and Herbaceae respectively, as he was obsessed with the distinction of woody and herbaceous habits.

4. Rosaceae

Rose family

110 genera, 3,100 species

Widespread but best represented in the Northern Hemisphere, mainly in the temperate and arctic climate.

Salient features: Herbs shrubs or trees, leaves usually serrate, stipules conspicuous, flowers actinomorphic, usually perigynous and with hypanthium, sepals and petals 5 each, petals usually clawed, well-developed nectar on hypanthium or base of stamens, stamens numerous, carpel single or numerous and free, rarely united, fruit usually fleshy.

Major genera: *Rubus* (750 species), *Potentilla* (500), *Prunus* (430), *Crataegus* (240), *Cotoneaster* (230), *Sorbus* (230), *Rosa* (225), *Alchemilla* (220), *Spiraea* (100), *Pyrus* (60), *Malus* (55) *Geum* (40) *and Fragaria* (15).

Description: Herbs (*Alchemilla, Fragaria*), shrubs (*Rosa, Rubus*) or trees (*Prunus, Malus, Pyrus*), rarely climbing (*some species of Rosa*), sometimes with runners (*Fragaria*), often with prickles and thorns, without latex, nodes trilacunar, rarely unilacunar. **Leaves** alternate, rarely opposite (*Rhodotypos*), simple (*Malus, Prunus*), palmately compound (*Fragaria*) or pinnate compound (*Sorbaria*), leaf blade often with gland-tipped teeth, usually serrate, venation pinnate or palmate, reticulate, stipules present, often adnate to petiole. **Inflorescence** with solitary flowers (*some species of Rosa*), racemes (*Padus*), panicles or cymose umbels (Spiraea), sometimes corymbs (*Crataegus*), rarely catkin-like (*Poterium*). **Flowers** bisexual, rarely unisexual (Poterium; plants monoecious or dioecious), actinomorphic, rarely zygomorphic (Parinarium), usually perigynous with distinct hypanthium (flat, cup-shaped or cylindrical); hypanthium free from or adnate to carpels, often enlarging in fruit, with nectar ring on inside, rarely epigynous (Malus). **Calyx** usually with 5 sepals, united at base, sometimes with 3-5 epicalyx (Fragaria) on outside, often persistent. **Corolla** usually with 5 petals, free, often clawed, imbricate. **Androecium** with numerous stamens, free, 4 in Sanguisorba, 2 in Parastemon urophylla, anthers bithecous, rarely monothecous (*Alchemilla*), dehiscence longitudinal, pollen grains tricolporate. **Gynoecium** with 1 (*Prunus*), 2-3 (*Crataegus*) to many carpels (*Rosa*), usually free, rarely connate (Crataegus, Pyrus), sometimes adnate to hypanthium, ovary superior or inferior, usually unilocular, ovules 1,2 or more, unitegmic or bitegmic, crassinucellate, placentation basal, lateral or apical, rarely axile (*Pyrus*). **Fruit** a follicle (*Spiraea*), achene (*Rosa*), drupe (*Prunus*), pome (*Malus*), or aggregate (etaerio of achenes in Potentilla, etaerio of drupes in Rubus); seed with straight embryo, without endosperm. Pollination mainly by insects. Dispersal by birds, animals or wind.

Economic importance: The family is largely known for its temperate fruits: apple (*Malus domestica*), pear (*Pyrus*), plums (*Prunusseveral species*), cherries (*Prunus avium, P. cerasus*) peaches (*Prunus persica*), almonds (*Prunus dulcis*), apricots (*Prunus armeniaca*), strawberry (*Fragaria vesca*), loquats (*Eriobotrya*), raspberries (*Rubus*), quince (*Cydonia*), etc. Popular ornamentals include species of Rosa, (*rose*) Rubus (*raspberry*), Chaenomeles (*flowering quince*), Potentilla (*cinquefoil*), Geum (*avens*), Cotoneaster, Crataegus (*hawthorn*), Pyracantha (*firethorn*), and Sorbus (*mountain ash*). Flowers of Rosa damascena are used for extracting attar of roses. The bark of Quillaja (soap-bark tree) contains saponin used as substitute for soap in cleaning textiles, and also yield tannin. Bark of Moquilla utilis (pottery tree) of Amazon is used in making heat-resistant pots. The wood of Prunus serotina is used for making furniture and cabinets. Several species are also valuable sources of timber.

Phylogeny: In spite of great morphological diversity the family Rosaceae is a well recognized group whose monophyly has been supported by rbcL sequences (Morgan et al., 1994). More than 27 family names have been proposed for groups of different genera taken out from Rosaceae, but according to Hutchinson (1973) if one or two tribes of the family are taken out, at least 18 or 19 should follow suit, and the Rosaceae would be reduced to the genus Rosa only. He like most recent authors follows a broader circumscription of the family, but does not recognize separation of Chrysobalanaceae and Neuradaceae (established as distinct in 12th edition of the Engler's Syllabus published in 1964). These two last families have been recognized as distinct in all major classifications. Cronquist places them together with Rosaceae under Rosales. Dahlgren places Chrysobalanaceae under Theanae—>Theales, but Neuradaceae along with Rosaceae in Rosales. Takhtajan places Neuradaceae in Rosales along with Rosaceae, but Chrysobalanaceae in distinct order Chrysobalanales. Thorne (1999) shifted both families from Rosidae to Dilleniidae, Chrysobalanaceae under Dillenianae—>Dilleniales and Neuradaceae under Malvanae—>Malvales. In later revisions (2003, 2006, 2007), however, he has abolished Dilleniidae. in his latest revision (2007) he placed Rosaceae under Rosidae—>Rosanae—>Rosales, Neuradaceae under Malvidae—>Malvanae—>Malvales—>Cistineaeand Chrysobalanaceae under Rosidae—>Podostemanae—>Euphorbiales. APG II and APweb have shifted Chrysobalanaceae to Eurosids I—>Malpighiales and Neuradaceae to Eurosids II—>Malvales, retaining Rosaceae in Eurosids I—>Rosales. The family has often been considered closely related to Saxifragaceae and Crassulaceae but the rbcL data identify Ulmaceae, Celtidaceae, Moraceae, Urticaceae and Rhamnaceae

as sister groups (Savolainen et al., 2000a). Usually 4 subfamilies are recognized within Rosaceae: Maloideae (fruit a pome), Amygdaloideae (syn: Prunoideae; fruit a drupe, carpel 1, nectaries on petiole and lamina), Rosoideae (fruit achenes or drupelets) and Spiraeoideae (follicle or capsule). Although Rosoideae and Maloideae are reasonable clades, little can yet be said of larger patterns of relationship in the rest of the family (Potter et al., 2002). Porteranthus is sister to Maloideae; Gillenia is sister to that whole clade (Potter et al., 2002; Evans et al., 2002a, b). The position of Dryadeae (inc. Cercocarpus, Dryas, Cowania and Chamaebatia) included in Rosoideae is uncertain, they lack phragmidiaceous rusts; their roots are associated with N-fixing Frankia and their fruits are achenes with hairy styles. They are rather basal *(Potter et al., 2002; Evans et al., 2002).*

5. Fabaceae

Bean or Pea family

(=**Leguminosae** A. L. de Jussieu)

630 genera, 18,000 species (Third largest family after Asteraceae and Orchidaceae) Cosmopolitan in distribution, primarily in warm temperate regions.

This large family has traditionally been divided into three subfamilies Papilionoideae (*Faboideae*), Caesalpinioideae and Mimosoideae. These have been recognized as independent families Fabaceae (*Papilionaceae*), Caesalpiniaceae and Mimosaceae in several recent systems of classification, a trend that tends to be reversing in last decade or so. It must be noted that name Fabaceae is valid for family sensu lato as well as for Papilionoideae upgraded as family. Leguminosae is the alternate name only for former whereas Papilionaceae is the alternate name for latter. Common features of the family include leaves usually compound with pulvinate base, odd sepal anterior, flowers perigynous, carpel 1 with marginal placentation and fruit commonly a pod or lomentum.

Subfamily Faboideae DC. (=Papilionoideae L. ex A. DC.)

B & H as Papilionoideae **Takhtajan, Thorne, APG II** and **APweb** as Faboideae

Cronquist and **Dahlgren** as family Fabaceae (Papilionaceae).

440, genera 12,800 species

Cosmopolitan in distribution, primarily in warm temperate regions.

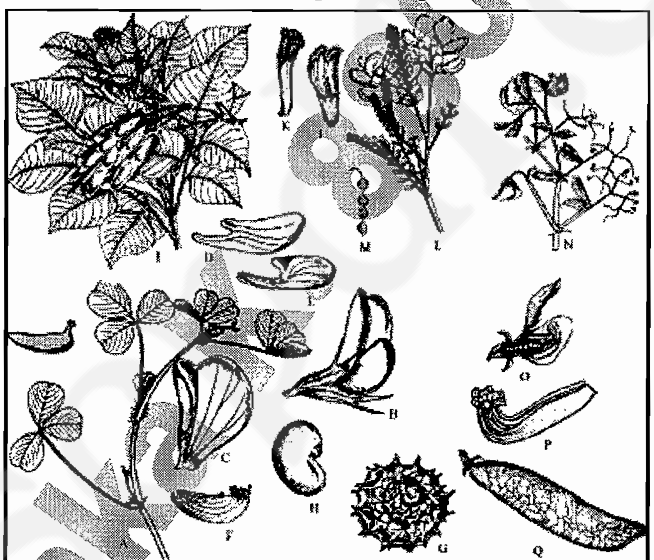

Figure-1: Fabaceae, *subfamily Faboideae*. Medicago polymorpha. **A:** Portion of plant with trifoliate leaves, laciniate stipules and few flowered axillary clusters on long peduncles; **B:** Flower; **C:** Standard; **D:** Wing; **E:** Keel; **F:** Androecium with diadelphous (1 free, 9 with united filaments) stamens; **G:** Fruit covered with tubercles; **H:** Seed. Dalbergia sissoo. **I:** Flowering shoot with a fruiting twig; **J:** Flower; **K:** Androecium with 9 monadelphous stamens. *Sophora mollis*. **L:** Branch with flowers; **M:** Moniliform pod. *Lathyrus odoratus*. **N:** Portion of a flowering branch, upper leaflets modified into tendrils; **O:** Vertical section of flower; **P:** Diadelphous andoecium; **Q:** Pod.

Salient features: Trees, shrubs or herbs, leaves usually pinnate compound with pulvinate base, flowers zygomorphic with papilionaceous corolla, sepals united, odd sepal anterior, stamens 10, usually diadelphous (1+(9)), carpel 1, ovary superior, fruit a pod.

Major genera: *Astragalus* (2000 species), *Indigofera* (700), *Crotalaria* (600), *Desmodium* (400), *Tephrosia* (400), *Trifolium* (300), *Dalbergia* (200), *Lathyrus* (150), *Lotus* (100), *and Milletia* (100).

Description: Trees (*Dalbergia, Erythrina*), shrubs (*Tephrosia, Alhagi, Indigofera*) or herbs (*Medicago, Melilotus*), sometimes woody climbers (*Wisteria*), commonly with root nodules. **Leaves** alternate, pinnately (*Pisum, Vicia*) or palmately compound (*Trifolium*), sometimes simple (*Alysicarpus, Alhagi*), whole leaf (*Lathyrus aphaca*) or upper leaflets (*Vicia, Pisum*) sometimes modified into tendrils, leaf base (*sometimes also the base of leaflets*) pulvinate, stipules present. **Inflorescence** racemose, in racemes, heads (*Trifolium*) or spikes

(*Ononis*), sometimes in clusters (*Lotus, Caragana*). **Flowers** bracteates (bracts often caducous), bisexual, zygomorphic, perigynous. **Calyx** with 5 sepals, more or less united, usually campanulate, odd sepal anterior. **Corolla** with 5 petals, free, papilionaceous consisting of a posterior standard or vexillum, two lateral wings or alae and two anterior petals fused along margin to form keel or carina which encloses stamens and pistil, posterior petal outermost. **Androecium** with 10 stamens, diadelphous (1 posterior free and filaments of nine fused into a tube which is open posteriorly), sometimes 5+5 as in Smithia, rarely monadelphous (*Ononis*), or free (Sophora, Thermopsis) anthers bithecous, dehiscence longitudinal. **Gynoecium** with a single carpel, unilocular with many ovules, placentation marginal, ovary superior, style single, curved. **Fruit** a legume or pod, rarely a lomentum (Desmodium), sometimes indehiscent (Melilotus), rarely spirally coiled (Medicago); seeds 1-many, seed coat hard, endosperm minute or absent, food reserves in cotyledons. Pollination primarily by insects, mostly bees. Dispersal is commonly by wind, but often exozoochorus (Medicago), or by mammals (Tamarindus).

Economic importance: The subfamily is of major economic importance, ranking second to Poaceae. It is the source of several pulse crops such as kidney bean (*Phaseolus vulgaris*), green gram (*P. aureus*), black gram (P. mungo), lentil (*Lens esculenta*), chick pea (*Cicer arietinum*), pea (*Pisum sativum*) and pigeon pea (Cajanus cajan). Soybean (Glycine max) and peanut (*Arachis hypogaea*) yield oil and high-protein food. Indigo dye is obtained from Indigofera tinctoria. The seeds of Abrus precatorius are used in necklaces and rosaries, but are extremely poisonous and can be fatal if ingested. The important fodder plants include alfalfa (*Medicago sativa*) and clover (*Trifolium*). Common ornamentals include lupin (*Lupinus*), sweet pea (*Lathyrus odoratus*), Wisteria (*Wisteria*), Laburnum, coral tree (*Erythrina*), false acacia (*Robinia*) and broom (*Cytisus*).

Subfamily Caesalpinioideae DC.

B & H, Takhtajan, Thorne, APG-II and **APweb** as Caesalpinioideae Cronquist and Dahlgren as family Caesalpiniaceae.

150 genera, 2,700 species

Distributed mainly in tropics and subtropics, a few species in the temperate regions.

Salient features: Trees, shrubs or herbs, leaves usually pinnate compound with pulvinate base, flowers zygomorphic corolla not papilionaceous, posterior petal innermost, sepals free, odd sepal anterior, stamens 10, usually free, in two whorls , ovary superior, carpel 1, fruit a pod.

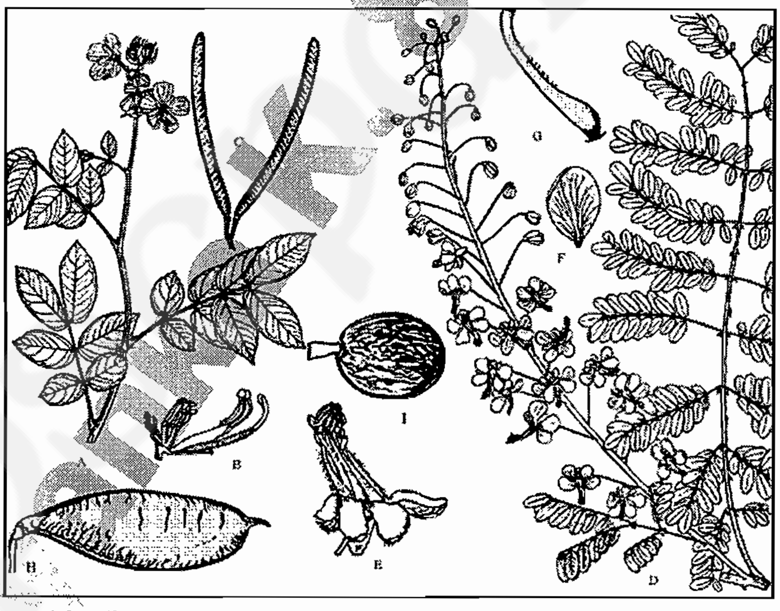

Figure-2: Fabaceae, *subfamily Caesalpinioideae. Cassia occidentalis.* **A**: Portion of plant with flowers and paripinnate leaves; **B**: Flower with sepals and petals removed, showing gynoecium and stamens of three different sizes; **C**: A pair of pods. *Caesalpiniadecapetala.* **D**: Portion of plant with bipinnate leaves and racemose inflorescence; **E**: Flower; **F**: One of the four large petals; **G**: Gynoecium; **H**: Pod; **I**: Seed.

Major genera: *Chamaecrisia (260 species), Bauhinia (250), Senna (250), Caesalpinia (120) and Cassia (30).*

Description: Trees (*Delonix*), shrubs (*Cassia occidentalis*) or herbs (*Cassia obtusa*), rarely woody climbers (*Pterolobium, Bauhinia*). Leaves alternate, pinnately or palmately compound, sometimes simple (*Bauhinia*), leaf base (sometimes also the base of leaflets) pulvinate, stipules present. **Inflorescence** racemose, in racemes or spikes (*Dimorphandra*). **Flowers** bracteate (bracts usually caducous) bisexual, zygomorphic, perigynous. **Calyx** with 5 sepals, rarely 4 (*Amherstia*), free or rarely connate (*Bauhinia*), odd sepal anterior.

Corolla with 5 petals, rarely 3 (*Amherstia*), 1 (*Pahuda*) or even absent (*Tamarindus*), free, not papilionaceous, posterior petal innermost. **Androecium** with 10 stamens, sometimes lesser (3 in Tamarindus), rarely more, free, sometimes unequal in size (Cassia), anthers bithecous, dehiscence longitudinal or by apical pores. **Gynoecium** with a single carpel, unilocular with many ovules, placentation marginal, ovary superior, style single, curved. Fruit a legume or pod, rarely a lomentum; seeds 1-many, seed coat hard, endosperm minute or absent, food reserves in cotyledons.

Economic importance: The Subfamily includes several ornamentals such as pride of Barbados (*Caesalpinia pulcherrima*), Paulo verde (*Parkinsonia*), red bud (*cercis canadensis*), Gul-mohar (*Delonix regia*), and several species of Cassia and Senna. Many species of Senna are cultivated for leaves that yield drug senna. The heartwood of Haematoxylon campechianum (logwood) yields the dye hematoxylin.

Subfamily Mimosoideae DC.

B & H, Takhtajan, Thorne, APG-II and **APweb** as Mimosoideae Cronquist and Dahlgren as family Mimosaceae.

40 genera, 2,500 species

Distributed mainly in tropical and subtropical regions.

Salient features: Trees, shrubs or herbs, leaves usually pinnate compound with pulvinate base, flowers actinomorphic, corolla not papilionaceous, petals valvate, sepals united, odd sepal anterior, stamens 4-many, free or connate, filaments often long exserted and showy, ovary superior, carpel 1, fruit a pod or lomentum.

Major genera: *Acacia* (1300 species), *Mimosa* (500), *Inga* (250), *Pithecellobium* (170), *Calliandra* (150) *and Albizia* (150).

Description: Trees (*Acacia, Albizia*), shrubs (*Calliandra*) or herbs (*Mimosa pudica*), rarely climbers (*Entada*), or aquatic plants (*Neptunia*). **Leaves** alternate, pinnately or palmately compound, sometimes simple, leaf base (sometimes also the base of leaflets) pulvinate, petiole sometimes modified into phyllode (*Acacia auriculiformis*), stipules present, sometimes spiny and hollow inside sheltering ants (*Acacia sphaerocephala*), leaves of Mimosa pudica sensitive to touch and showing sleeping movements. **Inflorescence** racemose, in racemes (*Adenanthera*) or spikes (*Prosopis*), sometimes in cymose heads (*Mimosa, Acacia*). **Flowers** small, bracteate (bracts usually caducous), sessile, or short-pedicelled, bisexual, actinomorphic, perigynous. **Calyx** with 5 sepals (4 in Mimosa), connate, odd sepal anterior, usually valvate, teeth small. **Corolla** with 5 petals (4 in Mimosa), free or united (Acacia, Albizia), valvate. **Androecium** with 4-many (4 in Mimosa, 10 in Prosopis, numerous in Acacia and Albizia) stamens, free (Acacia, Prosopis) or filaments connate (Albizia), anthers bithecous, dehiscence longitudinal, filaments long and anthers usually exserted. **Gynoecium** with a single carpel, unilocular with many ovules, placentation marginal, ovary superior, style single, curved. **Fruit** a legume or lomentum (Mimosa, Acacia); seeds 1-many, seed coat hard, endosperm minute or absent.

Economic importance: The subfamily is of lesser economic importance. Sensitive plant touch-me-not (*Mimosa pudica*) is grown as a curiosity. Various species of Acacia (*A. senegal, A. stenocarpa*) yield gum arabic. The pods and seeds of mesquite (*Prosopis juliflora*) are used as animal feed, wood in cooking meats. Wood of Xylia is hard and used in ship building. Calliandra, Dichrostachys are grown as ornamentals, Pithecellobium as a useful hedge plant.

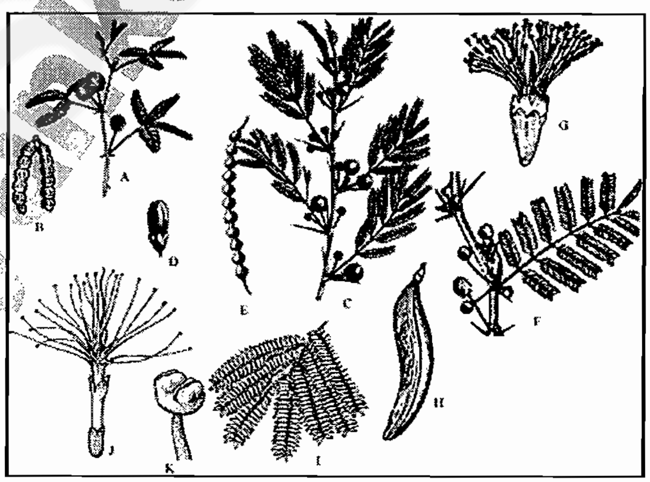

Figure-3: Fabaceae, subfamily Mimosoideae. *Mimosa pudica*. **A:** Branch with inflorescence heads; **B:** Lomentum fruits constricted between and splitting into 1-seeded segments. *Acacia nilotica.* **C:** Branch with long spines and inflorescence heads; **D:** Flower bud; **E:** Moniliform pod. *A. farnesiana.* **F:** Portion of a

branch with spines, leaf and inflorescence heads; **G**: Flower with numerous stamens; **H**: Pod. *Albizia julibrissin*. **I**: Part of a bipinnate leaf; **J**: Flower with monadelphous stamens; **K**: Part of a stamen showing anther.

Phylogeny of Fabaceae: The family is commonly circumscribed to include all the three subfamilies. Hutchinson as early as 1926 had recognized these as independent families Fabaceae, Caesalpiniaceae and Mimosaceae, a position that he maintained even in his last revision in 1973, regarding Caesalpiniaceae as the most primitive of the three, Mimosaceae relatively advanced and Fabaceae to be the climax group. The trend was followed and maintained in their latest classifications by Cronquist (1988) and Dahlgren (1989). Takhtajan who also began with the same treatment has in his last two versions (1987, 1997) included all the three under broadly circumscribed Fabaceae, giving these three the rank of subfamily. Thorne has consistently included all the three subfamilies under broadly circumscribed Fabaceae, a position also justified by APG-II. Thorne had earlier (1999) included Fabaceae along with 21 other families in a broadly circumscribed order Rutanae—>Rutales under suborder Fabineae (containing Fabaceae, Surianaceae and Connaraceae). In his latest revision (2003) he has placed Fabaceae, Surianaceae, Polygalaceae (earlier placed in Dilleniidae—>Geranianae—>Polygalales) and Quillajaceae (earlier with uncertain position) in separate order Fabales, a treatment similar to APG II and APweb. Affinities with Rutales have been supported on the basis of wood anatomy and embryology (Thorne, 1992). Thorne (2006, 2007) shifted the family under Rosanae—>Fabales. Recognition of broadly circumscribed Fabaceae, is supported by its monophyly as evidenced by common morphological features, and the results of rbcL sequence data (Chappill 1994; Doyle 1994). Studies also indicated that Caesalpinioideae are paraphyletic with some genera more closely related to Mimosoideae, and others to Faboideae than they are to one another. It is now established that Swartzia and Sophora (and relatives) represent basal clades of Faboideae lack a 50kb inversion in the trnL intron that is found in other members of the subfamily. Studies of Doyle et al., (2001) and Bruneau et al., (2001) suggest that Cercis and Bauhinia are basal in Fabaceae and as such discussed under distinct group Cercideae in APweb, characterized by simple leaves, sometimes bilobed; vestured pits, which they lack, are also absent in Cassieae. The flowers of Cercis are only superficially similar to those of Faboideae (Tucker 2002).

Mimosoideae are largely monophyletic, Faboideae are monophyletic, Caesalpinioideae are paraphyletic and basal. Wojciechowski et al., (2003) on basis of studies on sequences of the plastid matK gene note than non-protein amino acids seem to have originated once in this clade. Fabaceae s. l. are often referred to their own order, as in both Cronquist (1981) and Takhtajan (1997), former placing it closer to Rosales and latter closer to Sapindales. They can be confused with Connaraceae (Oxalidales), although the latter lack stipules, their flowers are radially symmetrical and have stamens of two distinctly different lengths, and their gynoecium is frequently multi-carpellate. However, in both the RP122 chloroplast gene has moved to the nucleus! Also, the ovaries of both have adaxial furrows (cf. the ventral slit: Matthews & Endress, 2002). Fabaceae have also been linked with Sapindaceae, in the Eurosid II group in APG-II and APweb.

6. Euphorbiaceae

Spurge family

321 genera, 7,770 species **(including Phyllanthaceae)**

Distributed widely in tropical and subtropical regions, with few species in temperate regions.

Salient features: Plants usually with milky latex, leaves alternate, flowers unisexual, carpels 3, ovary superior, 3-chambered, ovule with a caruncle.

Major genera: *Euphorbia* (2100 species), *Croton* (720), *Phyllanthus* (500), *Acalypha* (350), *Glochidion* (300), *Antidesma* (140), *Manihot* (160) *and Jatropha* (140).

Description: Herbs (some species of Euphorbia, Phyllanthus) shrubs (*Acalypha*) or trees (*Hevea*) with often milky or coloured latex, sometimes succulent and cactus-like, usually poisonous. **Leaves** alternate rarely opposite (some species of Euphorbia; Excoecaria) or whorled (*Mischodon*), sometimes modified into spines, simple or palmate compound, venation pinnate or palmate, reticulate, stipules present, sometimes modified into spines (*Euphorbia milii*) or glandular, rarely absent. **Inflorescence** of various types, commonly a cup shaped cyathium (Euphorbia) having a cup-shaped involucre with usually 5 nectaries along the rim and enclosing numerous male flowers (arranged in scorpioid cymes, without perianth and represented by a single stamen) and single female flower in the centre; sometimes a raceme (*Croton*) or panicle (*Ricinus*). **Flowers** unisexual (monoecious or dioecious), actinomorphic, hypogynous. **Perianth** usually with 5 tepals (representing sepals, petals absent), rarely 6 in two whorls (*Phyllanthus*) or absent (*Euphorbia*), petals usually absent but present in Jatropha and Aleurites, free or connate. **Androecium** with 1 stamen (*Euphorbia)*, 3 with fused filaments (*Phyllanthus*), 5 (*Bridelia*) or many (*Trewia*), sometimes polyadelphous (or with repeatedly branched filaments) as in Ricinus, anthers bithecous (sometimes monothecous in Ricinus due to splitting of filament), dehiscence longitudinal. **Gynoecium** with 3 united carpels, carpels rarely 4-many, ovary superior, trilocular with 1-2 ovules in each chamber, placentation axile, styles usually 3. **Fruit** a schizocarpic capsule, a regma (Ricinus), rarely a berry or drupe (Bridelia); seed often with conspicuous fleshy outgrowth called caruncle, embryo curved or straight, endosperm abundant or absent.

Economic importance: The family includes a number of valuable plants. Hevea brasiliensis (Para rubber tree) is the source of natural rubber. Rubber is also obtained from Manihot glaziovii (*ceara rubber*). Thick roots of Manihot esculentus (*cassava or tapioca*) are important source of starch in tropical regions. The leaves of Cnidoscolus chayamansa are used as vegetable. The fruits of Antidesma bunias are also edible. Aleurites moluccana (*candlenut tree*) and A. fordii (Tung tree) are sources of oils used in the manufacture of paints and varnishes. Oil similar to tung is also obtained from the species of Vernicia. Castor oil obtained from Ricinus communis is used as purgative. The common ornamentals include Euphorbia pulcherrima, E. milii, Acalypha hispida, Jatropha panduraefolia and Codiaeum variegatum. The fruit of Phyllanthus emblica (*'amla'*) is very rich source of vitamin C. The greasy tallow surrounding the seeds of Sapium sebiferum (Chinese tallow tree) is used for making soaps and candles.

Phylogeny: The family was earlier broadly circumscribed (*Bentham and Hooker*) to include genera which have now been separated under Buxaceae. Earlier considered related to Euphorbiaceae the family Buxaceae has been far removed to Sapindales (Engler and Prantl), Hamamelidales (Hutchinson), Buxales (*Takhtajan: under Caryophyllidae—>Buxanae*), or Balanopales (Thorne: under Rosidae—>Rosanae near Hamamelidales), Proteales (Judd et al.,: under core tricolpates), Buxales (APweb) or unplaced at the beginning of Eudicots (APG II). Cronquist is the only recent author to include Buxaceae next to Euphorbiaceae under Euphorbiales (Rosidae). The genus Ricinus is sometimes included under a separate family Ricinaceae but is more appropriately included under Euphorbiaceae. Webster (1967, 1994), who studied this family extensively recognized five subfamilies: Phyllanthoideae, Oldfieldioideae, Acalyphoideae, Crotonoideae and Euphorbioideae. These five are also recognized by Thorne (1999, 2003; 2007 prefers Hyaenanchoideae over Old fieldioideae). The former two on the basis of evidence from rbcL sequences have been separated into a distinct family Phyllanthaceae by APG-II and APweb, as they do not seem to form a clade with other members of Euphorbiaceae. Putranjiva, Lingelsheimia and Drypetes have been removed to Putranjivaceae, and Paradrypetes shifted to Rhizophoraceae. Rest of the Euphorbiaceae including last three subfamilies form a well-defined clade with single ovule in each chamber. Thorne (2003, 2006, 2007) has also recognized Putranjivaceae as distinct family. Sutter and Endress (1995) advocate a broadly delimited Euphorbiaceae (inc. both Phyllanthaceae and Putranjivaceae) but Huber (1991) for a narrower circumscription, with the biovulate taxa being considered to be closer to Linales. Within Euphorbiaceae s. str., molecular analyses by Wurdack and Chase (2002), suggest that substantial changes may be needed in the groupings recognized. Thorne had earlier (2003, 2006) included Euphorbiaceae under superorder Geranianae, but in his latest revision (2007) shifted it under Podostemanae.

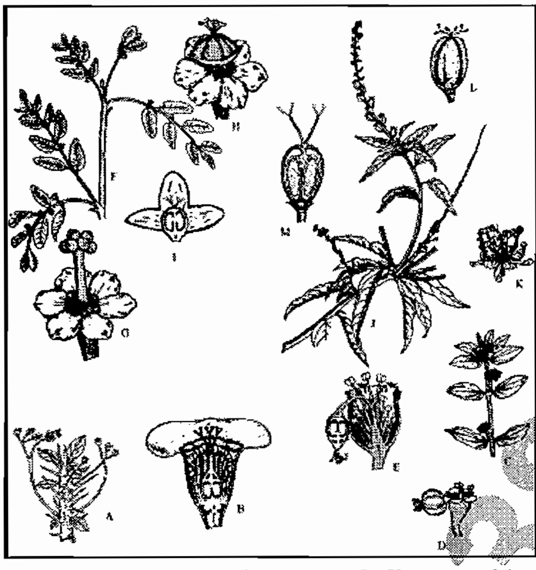

Figure-1 : Euphorbiaceae. *Euphorbia milii.* **A:** Branch with umbellate cyathia and spines; **B:** Vertical section of cyathium to depict showy scarlet bracts, single female flower and numerous male flowers, and nectaries along the rim of cyathium. *E. hirta.* **C:** Portion of plant showing opposite leaves and cyathia in heads; **D:** Cyathium with female flower protruding out and only 4 nectaries, showy bracts absent; **E:** Vertical section of cyathium. *Phyllanthus fraternus.* **F:** Portion of plant with flowers; **G:** Male flower with monadelphous stamens; **H:** Female flower; **I:** Vertical section of female flower. *Croton bonplandianum.* **J:** Portion of plant with flowers and fruits; **K:** Male flower with many stamens; **L:** Female flower; **M:** Vertical section of female flower.

7. Malvaceae

Mallow family

197 genera, 2,865 species (*excluding Grewiaceae*)

Distributed in tropical and temperate climates, mainly in the South American tropics.

Salient features: Herbs and shrubs with stellate pubescence, often mucilaginous, leaves palmately veined, stipules prominent, flowers usually with epicalyx, stamens numerous with united filaments, anthers monothecous, carpels five or more, ovary superior, placentation axile.

Major genera: *Hibiscus* (300 species), *Sterculia* (300), *Dombeya* (300), *Sida* (200), *Pavonia (200), Abutilon (100), Tilia (50), Adansonia (10), Gossypium (20) and Bombax (8).*

Description. Herbs or shrubs, rarely small (*Thespesia*) or large (*Tilia*) trees. Plants often mucilaginous. **Leaves** alternate, simple, sometimes palmately lobed (*Gossypium*), palmately veined, pubescence stellate or of peltate scales, stipules present. **Inflorescence** cymose (*Pavonia*) or flowers solitary axillary. **Flowers** bracteate (*Abutilon*) or ebracteate (*Hibiscus*) bisexual, actinomorphic, hypogynous. **Calyx** with 5 sepals, more or less united, often subtended by epicalyx (bracteoles), epicalyx 3 (*Malva*), 5-8 (*Althaea*) or absent (*Sida*). **Corolla** with 5 petals, free, imbricate, often adnate at base to staminal tube. **Androecium** with many stamens, filaments united into a tube (*monadelphous*), epipetalous, anthers monothecous, dehiscence transverse, pollen grains large with spinous exine, triporate or multiporate, tricolpate in Abutilon. **Gynoecium** with 2-many (*usually 5*) united carpels (*syncarpous*), multilocular (locules as many as carpels) with many ovules, placentation axile, ovary superior, styles branched above, stigmas as many as carpels or twice as many (Malvaviscus). **Fruit** a loculicidal capsule or schizocarp (Malva), follicles (*Sterculia*), rarely a berry (*Malvaviscus*); seeds 1-many, embryo curved, endosperm absent. Flowers are insect pollinated, nectar usually produced by inner surface of calyx. Dispersal may occur by wind, water, or animals. Large indehiscent pods of Adansonia are dispersed by large mammals.

Economic importance: The family is represented by several ornamentals such as China rose (*Hibiscus rosa-sinensis*), hollyhock (*Althaea rosea*) and rose of Sharon (*Hibiscus syriacus*), Young fruits of okra (*Hibiscus esculentus*; '*bhindi*') are used as vegetable. Cotton is obtained from different species of Gossypium. Cocoa (*chocolate source*) is obtained from seeds of Theobroma cacao, Cola nitida (both formerly under Sterculiaceae) yields cola. Seed hairs from Ceiba and Bombax (*kapok*) are used as stuffing. Tilia is a tree valuable as timber *(Basswood)*. The wood of T. cordata is particularly good for making furniture and musical instruments, also grown as ornamental tree.

Phylogeny: The family has been considered quite distinct on the basis of monadelphous stamens with monothecous anthers, though it had been considered quite closer to Tiliaceae, Bombacaceae and Sterculiaceae by Cronquist (1988) and Takhtajan (1997). These families share the features of presence of stellate hairs, mucilaginous cells, pericycle strands above phloem, similar size and pitting of vessels, and the distribution of xylem parenchyma. According to Judd et. al., (1999, 2002) the traditional distinctions between these families are arbitrary and inconsistent, and the merger of four would form a monophyletic Malvaceae. They however, concede that genera such as Grewia, Corchorus, Triumfetta, etc., form a clade which has lost calyx fusion, also suggesting that Grewioideae and Byttnerioideae form distinct clades within Malvaceae. Traditional Tiliaceae was circumscribed by free stamens and bithecous anthers. Thorne (1999, 2000), obviously had kept Tiliaceae distinct, merging the other two families with Malvaceae. Recent molecular evidence (*Alverson et al., 1998*) suggests that half-anthers of the traditional Malvaceae are transversely septate bithecous anthers that are strongly connate. Earlier Hutchinson (1973) had proposed that the monothecous anthers arose from splitting (chorisis) of the filaments. Restriction site analysis of cpDNA has established that genera with loculicidal capsules and numerous seeds (Hibiscus, Gossypium), form a basal paraphyletic complex. Genera with schizocarpic fruits, more than five carpels, and ovules one or two per carpel depict synapomorphies. APweb recognises following 9 subfamilies under the broadly circumscribes Malvaceae: Malvoideae, Bombacoideae, Sterculioideae, Tilioideae, Dombeyoideae, Brownlowioideae, Helicteroideae, Grewioideae and Byttnerioideae. Thorne who had earlier recognized Tiliaceae as distinct family has finally (2003, 2006) shifted Tilia and Craigia to Malvaceae under Tilioideae, the remaining genera of family Tiliaceae being put under new family Grewiaceae. He recognizes 7 subfamilies under Malvaceae, recognizing Grewioideae and Byttnerioideae as independent families Grewiaceae and Byttneriaceae, respectively. A major shift in his 2007 revision puts Malvanae under new subclass Malvidae.

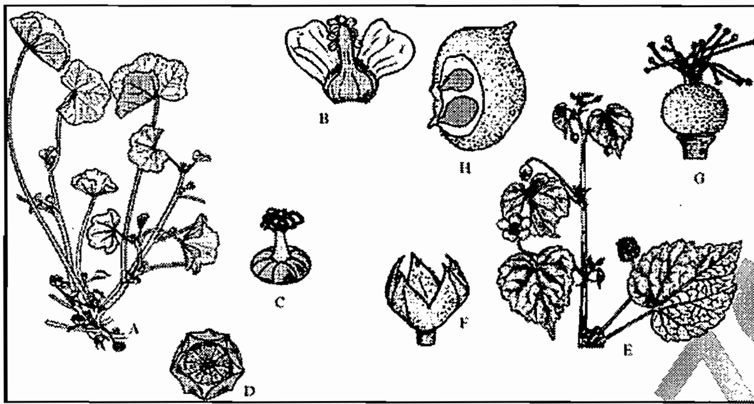

Figure-1: Malvaceae. *Malva parvifbra*. **A:** Plant in flower; **B:** Portion of flower with 2 petals and longitudinally split androecium; **C:** Gynoecium; **D:** Fruit with persistent calyx. *Abutilon indicum*. **E:** Plant with flowers and fruits on long peduncles; **F:** Calyx; **G:** Gynoecium with several carpels; **H:** One fruiting carpel split to show seeds.

8. Dipterocarpaceae

Meranti family

17 genera, 550 species

Distributed mainly in tropical Asia and Indomalaysia, also represented in Africa and South America.

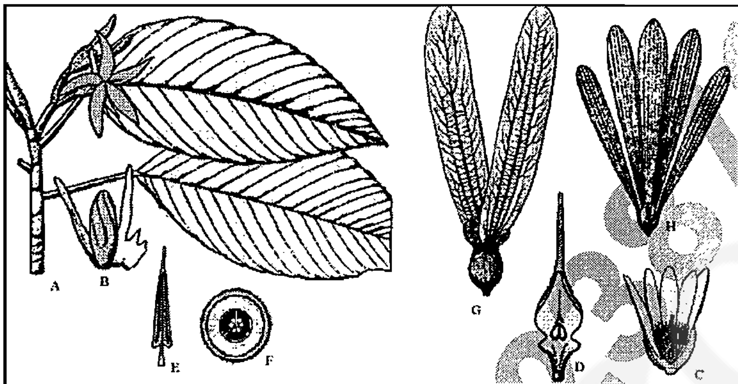

Figure-1: Dipterocarpaceae. *Dipterocarpus trinervis*. **A**: Branch with flower; **B**: Calyx and corolla; **C**: Vertical section of flower; **D**: Longitudinal section of ovary; **E**: Stamen with sterile tip above anther; **F**: Transverse section of ovary. **G**: Fruit of D. pilosus with two long wings. **H**: Fruit of Parashorea stellata with five wings.

Salient features: Small or large trees with buttressed bases, leaves evergreen, alternate, often with domatia, flowers perigynous or epigynous, in racemes or panicles, sepals becoming winged in fruit, petals 5, often leathery, anthers with sterile tips, carpels 3, fruit a winged nut.

Major genera: *Shorea* (150 species), *Hopea* (110), *Dipterocarpus* (80), *Vatica* (60) *and Monotes* (26).

Description: Small or large trees, often buttressed at the base, trunk very long and smooth, branched at top with cauliflowershaped crown, usually with special resin canals exuding aromatic dammar from wounds, nodes trilacunar or pentalacunar, roots with ectomycorrhiza. **Leaves** alternate, distichous, coriaceous, simple, evergreen, covered with fasciculate or stellate hairs, stipules present and frequently containing domatia housing insects, usually early shedding. **Inflorescence** racemose, axillary or terminal racemes or panicles. **Flowers** bisexual, actinomorphic, often showy, fragrant, hypogynous. **Calyx** with 5 sepals, free or slightly connate, sometimes enlarged and winged in fruit. **Corolla** with 5 petals, free or connate at base, spirally twisted, often leathery. **Androecium** with 5-numerous stamens, filaments free or connate at base, anthers bithecous, dorsifixed (Monotoideae), or basifixed (Dipterocarpoideae), dehiscence longitudinal, anthers with sterile tip formed by extension of connective, pollen grains tricolpate or triporate. **Gynoecium** with 3 united carpels, ovary superior or partly inferior (Anisoptera), 3-locular with 2 ovules in each chamber, placentation axile, ovules pendulus, anatropous, bitegmic, crassinucellate, only one ovule develops further. **Fruit** a single seeded nut with winged and membranous calyx; seeds without endosperm, cotyledons often twisted, enclosing radicle.

Economic importance: Many species of Dipterocarpus, Shorea, Hopea and Vatica usually grow together in tropical rain forests and are principal sources of hardwood timber. The wood is pale in colour and in great demand for plywood and block wood. Dammar resin obtained from the tree is used for special varnishes.

Phylogeny: The family is related to Ochnaceae, Elaeocarpaceae, Grewiaceae and other members of Malvales. Cronquist considers it closer to Guttiferae and Theaceae in addition to Ochnaceae. The family is usually divided into 3 subfamilies: Monotoideae, Pakaraimaeoideae and Dipterocarpoideae. Molecular studies of Kubitzki & Chase, (2002) have shown that Sarcolaenaceae, Cistaceae and Dipterocarpaceae form a well defined clade having plant with secretory canals, calyx imbricate, two outer members often different from the rest, filaments not articulated, ovules both anatro-pous and atropous; exotegmen curved inwards in chalazal region, and there is a strong case for merging former two in Dipterocarpaceae. Phylogenetic studies on family Dipterocarpaceae based on morphological and rbcL sequence data (Dayanandan et al., 1999) have shown that Monotoideae and Pakaraimaeoideae are cladistically basal, representing primitive members of the family. Thorne (2003) had earlier included the family (and the order Malvanae) under superorder Rosanae, but subsequently (2006) shifted to Malvanae.

9. Apiaceae

Carrot family

(=**Umbelliferae** A. L. de Jussieu)

440 genera, 3,590 species

Mainly distributed in north temperate regions.

Figure-1 : Apiaceae. *Coriandrum sativum.* **A**: Upper portion of plant with compound umbels in flower and fruit; **B**: Part of lower leaf with broader segments; **C**: Inner actinomorphic flower; **D**: Outer zygomorphic flower; **E**: Vertical section of flower; **F**: Cremocarp with persistent stylopodium at tip. Foeniculum vulgare. **G**: Portion of branch with compound umbels without bracts; **H**: Flower; **I**: Vertical section of flower; **J**: Cremocarp with forked carpophore separating 2 mericarps. Bupleurum candollii. **K**: upper portion of plant with simple entire leaves (rare situation in this family) and umbels; **L**: Cremocarp. **M**: Upper portion of plant of Eryngium biebersteinianum with spiny leaves and sessile head-like umbels.

Salient features: Aromatic herbs with hollow internodes, leaves compound with sheathing base, inflorescence umbel, petals incurved in bud, yellow or white, stamens 5, inflexed in bud, ovary inferior, fruit a cremocarp with stylopodium at apex.

Major genera: *Eryngium* (230 species), *Ferula* (150), *Pimpinella* (150), *Bupleurum* (100), *Heracleum* (60), *Sanicula* (40), *and Chaerophyllum* (40).

Description. Herbs with hollow internodes, commonly aromatic, rarely shrubs (Eryngium giganteum), or even climbers (Pseudocarpum), sometimes forming huge cushions (Azorella). Stems often fistular, with secretary canals containing ethereal oils and resins, coumarins, and terpenes, plants characteristically containing umbelliferose, a trisaccharide storage product. **Leaves** alternate, rarely opposite (Apiastrum), lobed or compound, rarely simple (Bupleurum), petioles with sheathing base, stipules absent. **Inflorescence** of simple or compound umbels, often subtended by involucre of bracts (involucre—bracts of umbel branches and involucel—bracts of flowers; absent in Foeniculum), sometimes like a head (Eryngium). **Flowers** small, bracteate or ebracteate (Foeniculum), usually pedicelled, rarely sessile (Eryngium) bisexual, rarely unisexual (Echinophora), actinomorphic (rarely zygomorphic), epigynous. **Calyx** with 5 sepals, adnate to ovary, 5-lobed, lobes often very small. **Corolla** with 5 petals, free, valvate or slightly imbricate, incurved in bud, notched at tip. **Androecium** with 5 stamens, free, inflexed in bud, exserted in open flower, rarely included, anthers bithecous, dehiscence longitudinal, pollen grains usually tricolpate. **Gynoecium** with 2 united carpels (syncarpous), with inferior ovary, bilocular with 1 ovule in each chamber, placentation axile, style surrounded at base by bilobed nectary, the basal portion of style along with nectary persisting in fruit as stylopodium. **Fruit** schizocarpic known as cremocarp splitting at maturity into two mericarps attached by a common stalk carpophore, mericarp containing oil canals called vittae inside. Seeds with small embryo, endosperm oily.

Economic importance: The family is the source of food plants, spices and condiments. Carrot (*Daucus carota*) and parsnip (*Pastinaca sativa*) are important root crops. Important flavouring plants include fennel *(Foeniculum vulgare)*, coriander (*Coriandrum sativum)*, caraway (*Carum carvi*), anise (*Pimpinella anisum)* and celery (*Apium graveolens*). Cicuta, Conium (hemlock, which Socrates is said to have used for suicide) and *Oenanthe* include poisonous plants.

Phylogeny: Apiaceae and Araliaceae have been considered as closely related families for a long time, often included in the same order (Bentham and Hooker, Engler and Prantl), a trend continued by almost all recent authors, though Hutchinson (1926, 1973) had separated the two under distinct orders, and even under different groups Lignosae and Herbaceae. This separation was arbitrary and as such in most recent classifications they are placed closer together under Araliales (Dahlgren; Takhtajan, Thorne) or Apiales (Cronquist, APG II, APweb), Monophyly of the family is supported by morphology, secondary metabolites, rbcL and matK sequences (Judd et al., 1994; Plunkett et al., 1997). Earlier studies (Judd et al., 1999) had indicated that Apiaceae are most closely related to Pittosporaceae, but recent data (APweb; Plunkett, 2001) points to Pittosporaceae being sister taxon of the whole group or Pittosporaceae may be embedded in Apiaceae + Araliaceae + other taxa. The family Apiaceae is usually divided into two subfamilies: Saniculoideae (Leaves often broad, with hairy or thorny leaf teeth, stylopodium separated from style by groove, fruit scaly or spiny, vittae often poorly developed) and Apioideae (umbels compound, stylopodium lacking groove, carpophore free, bifid, mericarps attached at apex). Recent molecular studies (Downie et al., 2000a, 2000b) have indicated that traditional division into tribes and genera may undergo substantial rearrangement. The genera formerly included in Hydrocotyloldeae (Including genera Hydrocotyle, Centella, etc.) form a polyphyletic group and as such have been segregated to Araliaceae (Hydrocotyle) and Mackinlaya- ceae (Centella, Trachymene, etc.) by Downie et al., (2000) and Chandler & Plunkett (2003; 2004, quoted in APweb). Stevens (APweb, 2003) points out that sampling must improve to resolve affinities especially with regard to Hydrocotyle and Trachymene. Thorne (2003), has shifted Centella and 5 other genera to Mackinlayaceae but placed Hydrocotyle and Trachymene in Araliaceae, recognizing only two subfamilies—Apioideae and Saniculoi- deae—under Apiaceae. Judd et al., (1999, 2002) argued that if Apiaceae and Araliaceae, in close to their traditional circumscriptions, were recognized, they would be poorly characterized morphologically, and certain genera would have no well-supported familial placement. They accordingly merge Aralia- ceae and Mackinlayaceae with Apiaceae, recognizing three subfamilies Aralioideae, Apioideae and Saniculoideae. Thorne (2003) and APG II (2003) treat all the three families as independent. APweb (2003 onwards) recognizes Araliaceae as an independent family, but relegates Mackinlayaceae to subfamily Mackinlayoideae, recognizing additional subfamily Azorelloideae (some former members of Hydrocotyloideae), thus recognizing a total of 4 subfamilies (other two being Apioideae and Saniculoideae), treatment followed by Thorne (2006, 2007).

10. Poaceae

Grass family

(= **Gramineae** A. L. de Jussieu)

678 genera, 10,230 species (Fourth largest family after Asteraceae, Orchidaceae and Fabaceae)

Worldwide, distributed from poles to equator and from mountain peaks to sea level, in all types of climates and habitats.

Salient features: Herbs or shrubs with hollow internodes and jointed stems, leaves distichous with distinct sheath enclosing the stem and linear blade with often a ligule at their junction, spikelet with two glumes, flowers reduced, enclosed in lemma and palea, perianth represented by lodicules, ovary superior, stigma feathery, fruit caryopsis.

Major genera: *Poa* (500 species), *Panicum* (450), *Festuca* (430), *Paspalum* (350), *Stipa* (300), *Bromus* (160), *Elymus* (150), *Sporobolus* (140), *Bambusa* (125), *Setaria* (100), *Arundinaria* (50) and *Chloris* (50).

Description: Herbs or rarely woody shrubs or trees (*bamboos*), often with rhizomes, stolons or runners, frequently tillering (branching from ground level) to form tufts of stems, stem (*culm*) with hollow internodes and jointed swollen nodes, with silica bodies. **Leaves** distichous, alternate, simple, with basal sheath surrounding internode and free linear blade, a ligule often present at the junction of blade and sheath, margins of sheath overlapping but not fused, sometimes united into a tube, venation parallel, leaf margins often rolled especially on drying, stipules absent. **Inflorescence** of spikelets arranged in racemes, panicles (*Poa, Avena*) or spikes (Triticum, Hordeum). Each spikelet with 2 (rarely 1 as in Monera) glumes enclosing 1 (Hordeum, Nardus) or more (Poa, Triticum) florets borne on an axis called rachilla, usually in 2 rows. **Flowers** small, reduced (*floret*), zygomorphic (due to only 2 lodicules displaced on one side), rarely actinomorphic, usually bisexual rarely unisexual (*Zea*), hypogynous, enclosed in lemma and palea (prophyll), lemma often bearing dorsal (*Avena*), subterminal (*Triticum*) or terminal (Hordeum) awn, or awn absent (*Poa*). **Perianth** absent or represented by 2 (rarely 3, as in Bambusa and Streptochaeta) lodicules. **Androecium** with usually 3, sometimes 6 (*Oryza*) or more (Arundinaria), rarely 1-2 (*Leptureae)* stamens, filaments free, anthers bithecous, basifixed, usually sagittate, dehiscence longitudinal, pollen grains monoporate. **Gynoecium** variously interpreted as bicarpellary, tricarpellary (with one reduced style), syncarpous or monocarpellary, unilocular with 1 ovule, placentation basal, styles 2, sometimes 3 (Bamboos and Streptochaeta), very rarely 1 (Anomochloa), stigmas often feathery. **Fruit** a caryopsis, rarely nut berry or utricle; seed fused with pericarp, embryo straight, endosperm starchy.

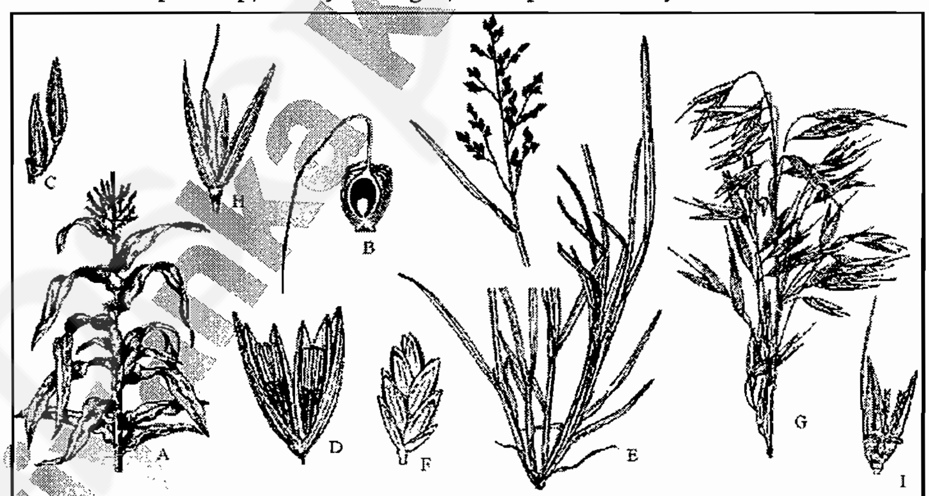

Figure-1: Poaceae. *Zea mays*. **A** Plant with terminal male Inflorescence and axillary female Inflorescence (Cob); B: Vertical section of female spikelet; **C**: Paired male spikelets; **D**: Male spikelet opened to show two fertile florets. *Poa annua*. **E**: Plant in flower; **F**: Spikelet. *Avena sativa*. **G**: Inflorescence; **H**: Spikelet opened; **I**: Fertile floret with awned lemma.

Economic importance: The family is of great economic importance, being a source of important cereals such as rice (*Oryza sativa*), wheat (*Triticum aestivum*) and corn or maize (*Zea mays*). The family also includes other food crops such as barley (*Hordeum vulgare*), pearl millet (*Pennisetum glaucum*), oats (*Avena sativa*), rye (*Secale cereale*) and sorghum (*Sorghum vulgare*). Grasses such as Cynodon, Axonopus and Agrostis are extensively used in lawns and turfs. Andropogon, Agropyron, and Phleum are major forage grasses.

Sugarcane (*Saccharum officinarum*) is the major source of commercial sugar. Bamboos are employed in big way in construction work, wickerwork and thatching in different parts of the world. Young bamboo shoots are used as food and often pickled. Lemon grass (*Cymbopogon*) leaves are distilled to yield essential oil for Imparting citronella scent. Grains of Coix lacryma-jobi (Job's tears) are use as necklace beads. Roots of Vetiveria zizanioides (*vetivar grass*) are used for making fragrant cooling pads and extraction of vetiver oil.

Phylogeny: Although a very large assemblage Poaceae are easily recognized and form a monophyletic group, as supported by morphology (*lodicules, spikelets with glumes, lemma and palea, fruit caryopsis*) and DNA characters (*rbcL and ndhF sequences*). Cronquist (1988) places Poaceae and Cyperaceae under the same order Cyperales, but similar morphology of two is believed to be due to convergent evolution, Cyperaceae being more closely related to Juncaceae (Judd et al., 1999). The studies of Bremer (2002), using rbcL and taq analyses found strong support for Cyperaceae, Juncaceae, and Thurniaceae forming cyperid clade and Poaceae along with other families forming a graminoid clade.

The nature of gynoecium in this family has been a matter of controversy. Most early authors including Haeckel (1883), Rendle (1930) and Diels (1936) considered it to consist of a single carpel terminated by 2-3 branched stigma. Lotsy (1911), Weatherwax (1929) and Arber (1934) considered that it represents tricarpellary ovary having evolved from an ovary with parietal placentation, a view supported by studies on floral anatomy (Belk, 1939). Others believe that gynoecium consists of 2-3 carpels (depending on the number of stigmas visible; Cronquist 1988, Woodland, 1991).

The family is variously classified by different authors. Hutchinson (1973) recognized two subfamilies Pooideae (with 24 tribes) and Panicoideae (with 3 tribes). Heywood (1978) recognized 6 subfamilies (Bambusoideae, Centostecoideae (should be Centothecoideae as the genus Centosteca on which the name is based is listed neither in Willis, 1973 nor Hutchinson, 1973), Arundinoideae, Chloridoideae, Panicoideae and Pooideae), further subdivided to include 50 tribes. Of these subfamilies, Centostecoideae occupies an isolated position although related to both Bambusoideae and Panicoideae, and includes broad-leaved herbs with single-to several-flowered spikelets. Studies of Clark et al., (1995) and Soreng and Davis (1998) suggest that Arundinoideae, Chloridoideae and Panicoideae form a well supported clade (often called PACC clade) based on embryological and DNA data. Arundinoideae as generally defined are not monophyletic, and many of their members such as Aristida, Phragmites, etc. are spread over in other two subfamilies. Chloridoideae and Panicoideae are generally found to be monophyletic. Stevens (APWeb, 2003) and Thorne (2003) listed 12 subfamilies under Poaceae: Anomochlooideae,

Pharoideae, Puelioideae, Panicoideae, Arundinoideae, Centothecoideae, Chlori- doideae, Aristidoideae, Danthonioideae (six forming **PACCAD** clade), Bambusoideae, Ehrhartoideae, Pooideae (**BEP** clade). Subsequently (APWeb 2008, Thorne 2006, 2007), however, they have added 13th Micrairoideae, probably sister to the whole clade (Thorne prefers Chondrosoideae to Chloridoideae). There is great diversity in the morphology and biochemistry of C4 photosynthesis in the family (Kellogg, 2000). Studies based on gene expression (Ambrose et al., 2000) indicate that the palea and perhaps even lemma are calycine in nature and the lodicules are corolline. Clark and Triplett (2006) discuss relationships within Bambusoideae, previously divided into the woody Bambuseae and the herbaceous Olyreae. However, the woody temperate bamboo group may be sister to the rest of the family. The duplication of AP1/FUL gene, apparently in stem-group Poaceae, may be involved in the evolution of the spikelet (Preston & Kellogg 2006). Malcomber and Kellogg (2005) suggest that there has been duplication of LOFSEP genes within Poaceae, while there has been a duplication of the whole genome in a clade that includes at least Zea, Oryza, Hordeum and Sorghum (Schlueter et al. 2004). Developmental gene duplication and subsequent functional divergence seem to have played a very

Important role In allowing the development of the baroque diversity of inflorescences in the family (Malcomber et al. 2006). Indeed, there has been very extensive duplication of genes-API, AG and SEP families - but not in the AP3 lineage (Zahn et al. 2005a).

Subclass 6. Ranunculidae (A)

Superorder 1. Proteanae (A)

Order 1. Proteales
- Family 1. Proteaceae

2. Platanales (B)
- 1. Platanaceae

3. Buxales (B)
- 1. Buxaceae
- 2. Didymelaceae

4. Sabiales (B)
- 1. Sabiaceae

Superorder 2. Ranunculanae

Order 1. Nelumbonales
- 1. Nelumbonaceae

2. Eupteleales (B)
- 1. Eupteleaceae

3. Paeoniales (B)
- 1. **Paeoniaceae**
- 2. Glaucidiaceae

4. Ranunculales

Suborder 1. Ranunculineae
- 1. Lardizabalaceae
- 2. Circaeasteraceae
- 3. Menispermaceae
- 4. **Berberidaceae**
- 5. Hydrastidaceae
- 6. **Ranunculaceae**

2. Papaverineae
- 1. Pteridophyllaceae (B)
- 2. **Papaveraceae**

11. Arecaceae

Palm family

(=**Palmae** A. L. de Jussieu)

189 genera, 2,350 species

Widespread in tropics of both hemispheres, a few in warm temperate regions.

Salient features: Woody shrubs or trees, trunk with scars of fallen leaves, leaves large, fan-shaped or pinnately compound, with sheathing bases, inflorescence paniculate, spathes often present, flowers small.

Major genera: *Calamus* (350 species), *Bactris* (180), *Pinanga* (120), *Licuala* (105), *Daemonorops* (100), *Areca* (60) and *Phoenix* (17).

Description: Trees or shrubs with unbranched trunk, rarely branched (*Hyphaene, Nypa*), with prominent scars of fallen leaves, sometimes spiny due to modified leaves roots or exposed fibres, sometimes rhizomatous, tannins and polyphenols often present, vascular bundles with hard fibrous sheath, apical bud well protected by leaf sheaths. **Leaves** alternate, usually forming a terminal crown, petiolate (petiole often with a flap called hastula at base), with pinnate (*feather palms*) or palmate (*fan palms*) segments, sometimes pinnately or twice pinnately compound, plicate (*folded like a fan*), blades rarely entire (*Licuala*); leaf segments folded V-shaped (*induplicate*) or inverted-V-shaped (*reduplicate*) in cross section; leaves sometimes very large sometimes over 20 m (Raphia fainifera with largest known leaf). **Inflorescence** axillary or terminal, often covered with spathes, a repeatedly branched panicle (Calamus) or almost spicate. **Flowers** bisexual (Licuala, Livistona) or unisexual with monoecious (Reinhardtia) or dioecious (Borassus, Rhapis) plants, flowers small, actinomorphic, usually sessile, trimerous, often with bracteoles connate below flowers. **Perianth** differentiated into sepals and petals, sometimes vestigial (Nypa). Sepals 3, free (*Arenga*) or connate (*Didymosperma*), usually imbricate. Petals 3, free or connate, usually valvate in male flower and imbricate in female flower (valvate in female flowers of Arenga). **Androecium** usually with six stamens in two whorls, sometimes numerous (*Reinhardtia, Howea*), rarely only 3 (*Nypia*), free, rarely with connate filaments (Nypa), anthers bithecous, basifixed or dorsifixed, rarely versatile, dehiscence by longitudinal slits; pollen grains usually monosulcate, smooth or echinulate. **Gynoecium** with usually 3 carpels, free or united, only 1 fertile in Phoenix, carpels sometimes many, ovary superior, placentation usually axile, rarely parietal (*Gronophyllum*), stigma usually terminal, sometimes lateral (*Heterospatha*) or basal (*Phloga*), ovules usually 1, rarely upto 3, orthotropous or anatropous. **Fruit** single seeded berry or drupe, exocarp often fibrous or covered with reflexed scales; seeds free or adhering to endocarp, endosperm present, embryo small. Largest seed in angiosperms formed in double coconut (*Lodoicea maldivica*).

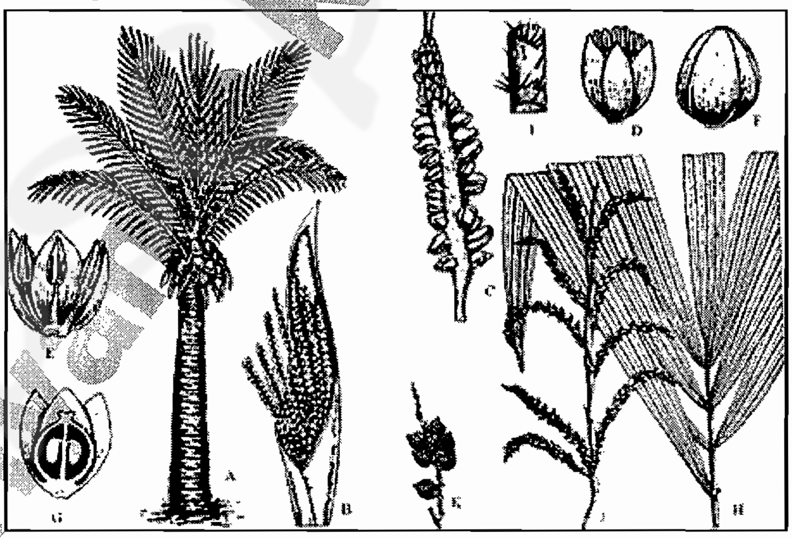

Figure-1: Arecaceae. *Cocos nucifera* **A**: Habit; **B**: Inflorescence; **C**: Branch of inflorescence with female flowers towards base, male flowers towards the top; **D**: Male flower; **E**: Vertical section of male flower; **F**: Female flower; **G**: Vertical section of female flower. *Calamus pseudotenuis*. **H**: Vegetative branch; **I**: Portion of stem showing thorns; **J**: Male inflorescence; **K**: Female inflorescence.

Economic importance: The family is of great economic importance. Most useful member is Coconut palm (*Cocos nucifera*), with almost every part put to use. Mesocarp of the fruit is the source of coir fibre, the seed endosperm (*copra*) yielding coconut oil, and the leaves used in thatching, basket making and a variety of toys and decoration articles. Palm oil is extracted from Elaeis guineensis). Sago, a major source of carbohydrate food is obtained from Metroxylon sagu (*sago palm*) and some species of Arenga and Caryota. Palm wine (*toddy*) is obtained from species of Borassus and Caryota. Fibre is also extracted from many species of palms particularly belonging to Raphia (*raffia)*, Caryota (*kitul fibre*) and Leopoldinia (Piassava fibre). Dates are obtained from Date palm (Phoenix dactylifera). Vegetable ivory is obtained from the seeds of ivory nut palm (Phytelephas macrocarpa) and was once used for buttons and as a substitute for real ivory. Waxes are obtained from Copernicia (*carnauba wax*) and Ceroxylon. Betel nut are obtained from Areca catechu of Africa and Southeast Asia. The family also contributes a large number of ornamentals such as Royal palm (Roystonea regia), fishtail palm (*Caryota*), Chinese fan palm (Livistona), and cabbage palm (Sabal). Various species of Calamus are source of commercial cane used in furniture and polo sticks.

Phylogeny: In spite of being very large and diverse, and often divided into numerous subgroups, the family is distinct, easily recognized and monophyletic. APweb (2005) recognizes 5 subfamilies: Calamoideae, Nypoideae, Coryphoideae, Ceroxyloideae and Arecoideae. Thorne (2007) adds sixth Phytelephoideae segragated from Ceroxyloideae. Uhl et al., (1995) carried out cladistic analysis of the family using morphological data as well as cpDNA restriction site analysis and found support for placement of Nypa (Nypoideae) a sister of rest of the palms. More recent studies of Asmussen et al., (2000) indicated that Nypoideae + Calamoideae (strong support) + the rest of the family (moderate support) form a basal trichotomy; other characters support these general relationships. However, other work suggests that details of the relationships of Nypoideae and Calamoideae to the rest of the family are unclear, and some morphological groupings are not supported by molecular data (Hahn 2002).

12. Liliaceae

Lily family

15 genera, 640 species

Widely distributed in the Northern Hemisphere, mainly in the temperate regions.

Salient features: Herbs with alternate or whorled leaves, base sheathing, flowers not subtended by spathaceous bracts, flowers bisexual, trimerous, perianth with 6 petaloid tepals, stamens 6, filaments free, carpels 3, united, ovary superior, placentation axile, fruit a capsule.

Major genera: *FritLUaria (90 species), Gagea (80), Tulipa (80) and Lilium (75).*

Description: Perennial herbs with underground bulb, generally with contractile roots. **Leaves** mostly basal, alternate or whorled, usually linear or strap shaped, simple, entire venation parallel, stipules absent. **Inflorescence** usually racemose (*Lilium*), sometimes solitary (*Tulipa*) or subumbellate (*Gagea*). **Flowers** showy, bisexual, actinomorphic, rarely zygomorphic, trimerous, hypogynous. **Perianth** with 6 tepals, in two whorls (outer representing sepals, inner petals), both whorls petaloid, often spotted or with lines, often united into tube, nectary at the base of tepal. **Androecium** with 6 stamens, in 2 whorls, epiphyllous, filaments free. **Gynoecium** with 3 carpels, united, ovary superior, trilocular with many ovules, placentation axile, styles simple with 3-lobed stigma. **Fruit** a loculicidal capsule, rarely a berry; seeds usually flat, with well-developed epidermis, seed coat not black, small embryo, endosperm copious. Pollination by insects, especially bees, wasps, butterflies. Seeds are dispersed by water or wind.

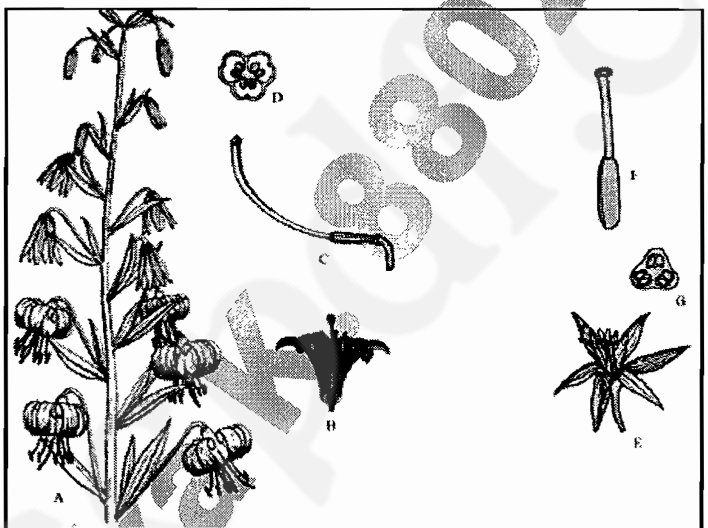

Figure-1: Liliaceae. **A:** Flowering portion of Lilium polyphyllum. **B:** Longitudinal section of flower of L. canadense. **C:** Gynoecium of L. lancifolium. **D:** Transverse section of ovary of L. lancifolium. Gagea pseudoreticulata. E: Flower; **F:** Gynoecium; **G:** Transverse section of ovary. (A, after Polunin and Stainton, Fl. Himal., 1984)

Economic importance: The family is important for its valuable ornamentals such as lily (*Lilium*), tulip (*Tulipa*) and Fritillaria (*Fritillary*).

Phylogeny: The circumscription of the family has undergone considerable reduction over the recent years. The genera formerly included under the family have now been removed to diverse families: Colchicum (Colchicaceae—with corm), Trillium (Trillia-ceae—rhizome, leaves whorled, perianth with sepals and petals), Allium (Alllaceae—bulb, inflorescence umbellate, with spathaceous bracts, smell of onion, seeds black), Asphodelus and Aloe (Asphodela- ceae—inflorescence racemose, seeds black, leaves succulent, often with coloured sap), Asparagus (Asparagaceae—fruit a berry, leaves rudimentary, seeds black), Ruscus (Ruscaceae—leaves scarious, filaments connate), the last four were taken under a separate order Asparagales along with several other families, in the recent APG II and APweb classifications. Thorne had earlier (1999, 2000) included these four families (along with other splitters from broadly circumscribed Liliaceae) under order Orchidales, but has shifted (2003) these together with others to order Iridales, also bringing about certain changes in circumscription (Ruscaceae and Convallariaceae included under Asparagaceae). In 2006, 2007 revisions he has slightly enlarged the circumscription of family Liliaceae by merging Tricyrtidaceae and Calochortaceae, but has divided the family into four subfamilies Medeoloideae (1 genus), Lilioideae (9 genera), Tricyrtidoideae (4 genera) and Calochortoideae (1 genus). The narrow

circumscription of the family was first suggested by Dahlgren (1985), and forms a monophyletic group as confirmed by the cladistic studies of Chase et al., (1995a, 1995b). Cronquist, on the other hand, broadened the circumscription of the family, also including, in addition to the above families, large family Amaryllidaceae within Liliaceae.

13. Orchidaceae

Orchid family

788 genera, 18,500 species **(Second largest family after Asteraceae)**

Widely distributed, most common in moist tropical forests (where frequently epiphytic), also well distributed in subtropics and temperate regions.

Salient features: Herbaceous perennials, roots with velamen, leaves distichous, flowers trimerous, zygomorphic, corolla with 2 lateral petals and labellum, pollen in pollinia, ovary inferior, seeds minute.

Major genera: *Pleorothallus (1100 species), Bulbophyllum (970), Dendrobium (900), Epidendrum (800), Habeneria (580), Liparis (320), Malaxis (280), Oberonia (280), Calanthe (1000), Vanilla (100) and Vanda (60).*

Description: Perennial herbs, terrestrial (*Malaxis, Orchis*), epiphytic (*Oberonia, Dendrobium*) or saprophytic (Gastrodia, Epigonium), rarely climbers (Vanilla), with rhizomes, tuberous roots, corms or rootstock, roots mycorrhizal, with multiseriate epidermis of dead cells known as velamen. Stems foliate or scapose, base often thickened to form pseudobulb, aerial roots present. **Leaves** usually alternate, distichous, rarely opposite, sometimes reduced to scales, often fleshy, simple, entire, sheathing at base, sheath closed and encircling stem, venation parallel, stipules absent, stomata tetracytic. **Inflorescence** racemose, spicate or paniculate, sometimes with solitary flowers, rarely cleistogamous. **Flowers** usually bisexual, very rarely unisexual, zygomorphlc, usually showy, often twisted 180o during development (resuplnate), **Perianth** differentiated into sepals and petals. Sepals 3, free or connate, usually petaloid, imbricate, similar or dorsal smaller, lateral more or less adnate to the ovary. Petals 3, free; middle petal forming labellum or lip, often spotted and variously coloured, sometimes saccate or even spurred at base; lateral petals similar to sepals. **Androecium** with usually 1 stamen, sometimes 2 (Apostasia) or 3 (Neuwiedia), adnate to style and stigma forming a column (gynostemium) opposite the lip, anther sessile on column, bithecous, dehiscence by longitudinal slit, introrse; pollen grains powdery or waxy, agglutinated into pollinia, each pollinium with a sterile portion called caudicle, 2 to 8 pollinia formed in a flower. **Gynoecium** with 3 united carpels, ovary inferior, unilocular with parietal placentation, rarely 3-locular with axile placentation (Apostasia), stigmas 3, one often transformed into a sterile ros- tellum, latter often having a sticky pad called viscidium attached to the pollinia; ovules numerous, minute, anatropous, tenuinucellate. **Fruit** a loculicidal capsule or a sausage-shaped berry; seeds numerous, minute, embryo very minute, endosperm absent. Pollination mostly by insects such as bees, wasps, moths and butterflies. Flowers of Ophrys resemble the female wasp and the pollination results from pseudocopulation, male wasp attracted by the shape and smell of the flowers, mistaking it for a female wasp. Tiny dust-like seeds are dispersed by wind.

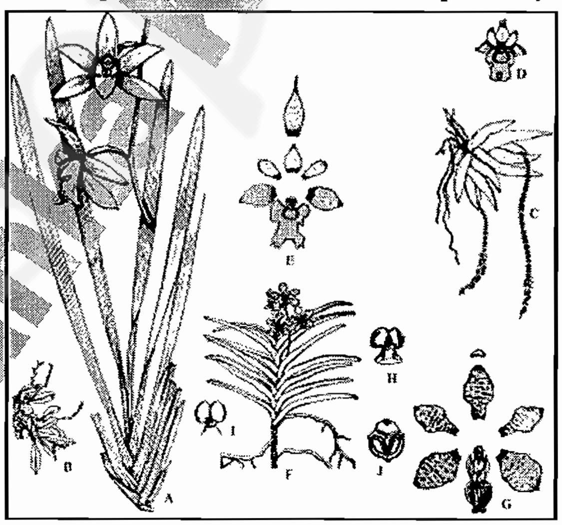

Figure-1: Orchidaceae. A: Cymbidium hookeranum with leaves and flowers. **B:** Eria muscicola, plant with inflorescences. *Oberonia recurva*. **C:** Epiphytic plant with ensiform leaves and pendulous inflorescence; D: Flower; **E:** Floral parts separated showing from above downwards bract, three sepals, two lateral petals and anterior labellum. *Vanda tessellata*. **F:** Epiphytic plant with inflorescence; **G:** Floral parts separated; **H:** Pol- linia from behind with gland and strap; **I:** Pollinia from front; **J:** Operculum from inside.(After Dassanayake and Fosberg, Fl. Ceylone, vol 2, 1981)

Economic importance: The family is known for large number of ornamentals reputed for their showy flowers mainly *Cattleya, Dendrobium, Cymbidium, Epidendrum, Vanda, Coelogyne* and *Brassia.* The only food product from the family is vanilla flavouring obtained from the fruits *Vanilla planifolia.*

Phylogeny: The family is generally considered as a natural group, the monophyly of the family supported by morphology and rbcL sequences (Dressler, 1993; Dahlgren et al., 1985). The family is commonly divided into three subfamilies: Apostasioideae, Cypripedioideae, and Orchidoideae. The former two include one tribe each, but the last one, which includes nearly 99 per cent of the orchid species is divided into 4 tribes. Apostasioideae are considered to be sister to the remaining orchids (Dressler, 1993; Cameron et al., 1999), and monophyletic as supported by vessel-elements with simple perforations and distinctive seed type. Cypripedioideae are usually considered clearly monophyletic (Judd et al., 1999) as supported by their saccate labellum, two functional stamens and absence of pollinia. Members of Orchidoideae share acute anther apex, soft stems and lack silica bodies. More recently however 5 subfamilies are recognized the other two being Vanilloideae and Epidendroideae (APweb, Thorne, 2003, 2006). The recent studies have, however, put some uncertainty over the position of Cypripedioideae. For instance, they may group (*albeit weakly*) with Vanilloideae (Freudenstein & Chase 2001) or be sister to Orchidaceae minus Apostasioideae (Cameron 2002; Stevens, 2003). Relation-ships within Orchidoideae are becoming fairly well resolved (Cameron 2004). Thorne (2006, 2007) recognizes 6 subfamilies: Apostasioideae, Neuwiedioideae, Cypripedioideae, Orchidoideae and Epidendroideae.

14. Verbenaceae

Verbena family

36 genera, 1,035 species (including only Verbenoideae)

Widely distributed, mainly in tropical regions, also in temperate regions, prominent in new world

Salient features: Plants aromatic, leaves opposite, serrate, stem often angular, nonglandular hairs if present unicellular, flowers zygomorphic, in racemes, spikes or heads, pollen exine thickened near apertures, style simple with bilobed stigma, stigmatic area conspicuously swollen and glandular, ovary with four ovules, ovules attached to the margin of false septa.

Major genera: *Verbena* (200), *Lippia* (180) *Lantana* (140), *Citharexylum* (65), *Glandularia* (55), *Duranta* (28) *and Phyla* (10).

Description: Aromatic herbs (*Lippia*), shrubs (*Lantana*), sometimes trees, rarely lianas, sometimes with prickles or thorns, stem usually 4-angled, often with iridoids and phenolic glycosides, usually with glandular hairs, nonglandular hairs if present unicellular. **Leaves** opposite, sometimes whorled, simple or sometimes lobed, usually aromatic, entire to serrate, stipules absent. **Inflorescence** racemose: racemes, spikes or heads. **Flowers** bisexual, zygomorphic, hypogynous. **Calyx** with 5 sepals, united, tubular to campanulate, persistent, sometimes enlarged in fruit. **Corolla** with 5 petals, sometimes appearing 4 due to fusion of two posterior petals, united, weakly bilabiate, lobes imbricate. **Androecium** with 4 stamens, epipetalous, didynamous, inserted in corolla tube, filaments free, dehiscence longitudinal. pollen grains tricolpate, exine thickened near apertures. **Gynoecium** with 2 united carpels, ovary superior, bilocular, ovules 2 in each chamber, finally 4-locular due to false septum with 1 ovule in each chamber, unitegmic, axile placentation, ovary not or slightly 4-lobed, style 1, terminal, style simple with bilobed stigma, stigmatic area conspicuously swollen and glandular, ovary seated on a nectary disc. **Fruit** a drupe with 2 or 4 pits, or schizocarp splitting into 2 or 4 nutlets; seed with straight embryo , endosperm absent. Pollination by insects. Dispersal by birds, wind or water.

Economic importance: The family contributes some ornamentals such as Verbena, Lantana, Duranta, and Glandularia. Lippia (lemon verbena) and Privea are used as herbal teas or yield essential oils. Verbena officinalis (vervain) is used for a number of herbal remedies including treatment of skin diseases.

Phylogeny: The family is closely related to Lamiaceae. The circumscription of the family has undergone considerable revision with several genera (nearly two-thirds) from older Verbenaceae such as *Clerodendrum*, *Callicarpa*, *Vitex* and *Tectona transferred* to Lamiaceae (Judd et al., 2002; Thorne, 2000, 2003; APG II, APweb). The family is now circumscribed to include only subfamily Verbenoideae. The traditionally delimited Verbenaceae are paraphyletic and Lamiaceae polyphyletic. With narrowly defined Verbenaceae and broadly defined Lamiaceae, both become monophyletic. The family is distinguished from Lamiaceae in racemose inflorescence, ovules attached on margins of false septa, style simple with conspicuous bilobed stigma, pollen exine thickened near apertures, hairs unicellular, weakly bilabiate corolla and usually terminal style. Phryma (Phrymaceae) with one carpel aborted and ovary with single basal ovule may be closely related to Verbenaceae (Chadwell et al., 1992). Avicenna often included in distinct family or broadly circumscribed Verbenaceae is more appropriately included in Acanthaceae (APweb). Thorne (2003) treats Phrymaceae and Avicennlaceae as distinct families.

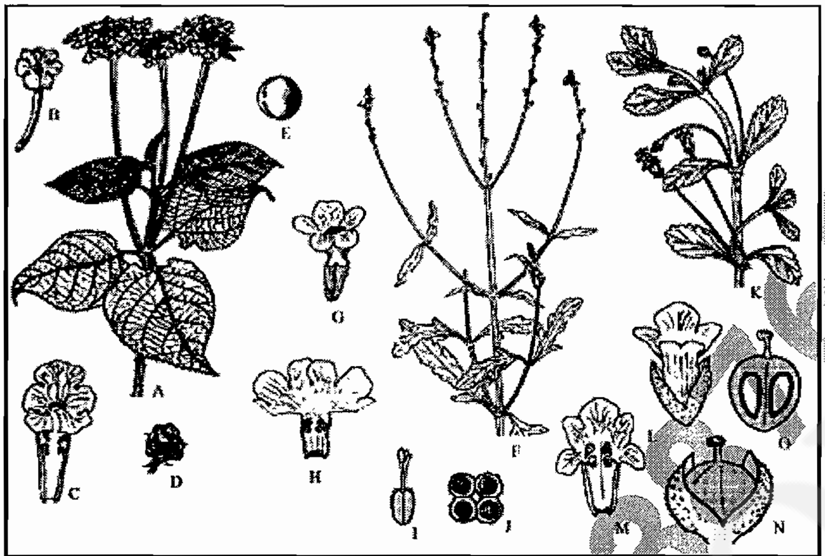

Figure-1 : Verbenaceae. *Lantana camara*. **A** Branch with ovoid compact inflorescences on long peduncles; **B**: Flower with long corolla tube and zygomorphic limb; **C**: Corolla spread out to show epipetalous stamens; **D**: Cluster of fruits; **E**: Fruit. **Verbena officinalis**. **F**: Plant with terminal spikes; **G**: Corolla with shorter broader tube and zygomorphic limb; **H**: Corolla spread out to show epipetalous stamens; **I**: Gyno- ecium; **J**: Transverse section of ovary with 4 one-seeded chambers. ***Phyla nodiflora***. **K**: Portion of plant with pedunculate globose inflorescences; **L**: Flower with short broad tube and zygomorphic limb; **M**: Corolla spread out to show epipetalous stamens; **N**: Fruit with persistent calyx; **O**: Longitudinal section of fruit.

15. Solanaceae

Nightshade or Potato family

98 genera, 2,715 species

Cosmopolitan in distribution, found both in temperate and tropical climates with largest concentration in Central and South America.

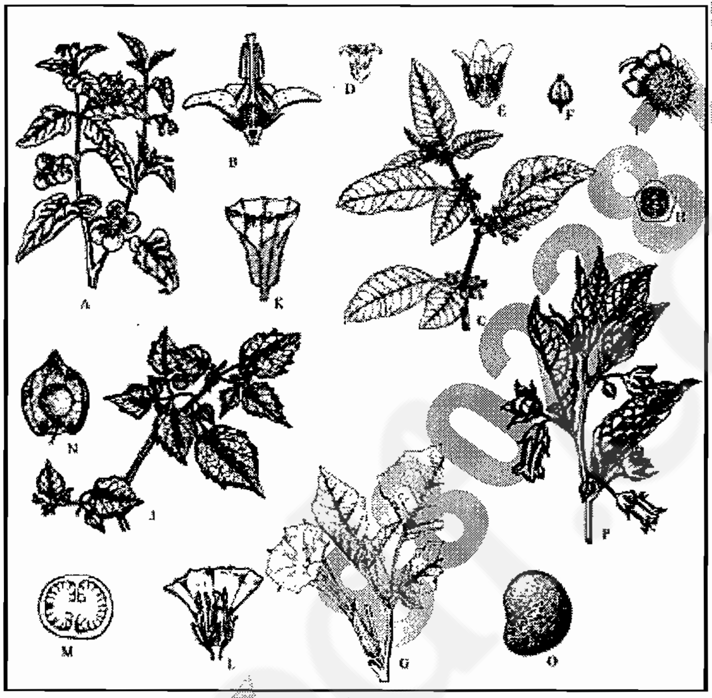

Figure-1 : Solanaceae. *Solanum nigrum*. **A:** Branch with extra-axillary rhipidium infloresences and fruits; **B:** Vertical section of flower. *Withania somnifera*. **C:** Branch with axillary cymose clusters of flowers; **D:** Flower; **E:** Vertical section of flower with bell-shaped corolla; **F:** Fruit enclosed in enlarged urceolate calyx. *Datura inoxia*. **G:** Branch with axillary funnel-shaped flowers; **H:** Transverse section of ovary, tetralocular due to false septum; **I:** Capsule covered with tubercles and basal persistent portion of calyx. *Physalis minima*. *J:* Portion of plant with flowers; **K:** Flower; **L:** Vertical section of flower; **M:** Transverse section of ovary with swollen placentae; **N:** Fruit with inflated calyx removed from one side; **O:** Seed; **P:** Flowering branch of Atropa belladona.

Salient features: Leaves alternate, stipules absent, flowers actinomorphic, stamens 5, carpels 2, ovary superior, 2-chambered, placenta swollen, septum oblique, ovules numerous, fruit a berry or capsule.

Major genera: *Solanum* (1350 species), *Lycianthus* (190), *Cestrum* (160), *Nicotiana* (110), *Physalis* (95), *Lycium* (90), *Capsicum* (50), *Hyoscyamus* (25) *and Datura* (10).

Description: Herbs, shrubs (*Brunfelsia*, *Cestrum*) or small trees (*Solanum verbascifolia; Dunalia*), rarely lianas, often poisonous, sometimes with prickles, underground tubers in Solanum tuberosum (potato), vascular bundles with both outer and Inner phloem. **Leaves** alternate, simple, rarely pinnately compound (potato), stipules absent, paired leaves adjacent on the stem are common. **Inflorescence** cymose (Solanum) or of solitary flowers (*Datura*). **Flowers** bisexual, actinomorphic, hypogynous. **Calyx** with 5 sepals, united, persistent, sometimes enlarged and swollen in fruit (Withania, Physalis). **Corolla** with 5 petals, united, rotate (*Solanum*) or tubular (*Oestrum*), rarely funnel shaped (*Datura*) or bilabiate (*Schizanthus*). **Androecium** with 5 stamens epipetalous, inserted in corolla tube, filaments free, bithecous, anthers introrse, dehiscence longitudinal or by apical pores. **Gynoecium** with 2 carpels, rarely 3-5 (*Nicandra*), united, ovary superior, bilocular, axile placentation, placenta swollen, septum oblique, ovary often further divided by false septa, style 1, rarely gynobasic (*Nolana*), stigma bilobed, ovary seated on a nectary. **Fruit** berry or capsule (*Datura*); seeds many, embryo straight, endosperm present. Pollination mostly by insects. Dispersal mostly by birds.

Economic importance: The family includes a number of food plants such as tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), egg plant or brinjal (*S. melongena*), ground cherry (*Physalis peruviana*). Peppers (*Capsicum annuum*) are used both as a food source (*young*) and spices (*ripe*). Many

poisonous species are important drug plants such as Atropa belladona (*atropine*), Hyoscyamus Niger (*henbane-hypnotic drug*), Datura stramonium (*stramonium)* and Mandragora officinarum (*mandrake*). Tobacco (*Nicotiana tabacum and N. rustica*) contains toxic alkaloid nicotine and is grown for chewing, smoking and snuff. Some ornamental genera include *Brunfelsia* (*lady-of-the-night; yesterday-today-and tomorrow*), Oestrum (*'Rat ki Rani'; night blooming jessamine*), Petunia, Physalis (*ground cherry*) and Solanum (*nightshade*).

Phylogeny: The family is closely related to Scrophulariaceae from which it is differentiated in vascular bundles having outer and inner phloem, actinomorphic flowers and oblique septum of the ovary. Schizanthus with zygomorphic flowers is borderline genus. The family also has close affinities with Convol- vulaceae, Boraginaceae and Gesneriaceae. Nolanaceae with gynobasic style and lobed ovary has been merged with Solanaceae. The following 7 subfamilies are recognized (Olmstead et al., 1999; APweb, 2003): Schwenckioideae (pericycle fibres present, stamens 4, didynamous, or 3 staminodes; embryo straight, short), Schizanthoideae (pericycle fibres absent, flowers zygomorphic, anterior petals connate, forming a keel, stamens 2, staminodes 3, embryo curved), Goetzeoideae (Fruit often a drupe, embryo curved: Takhtajan as family Goetzeaceae), Cestroideae (pericyclic fibres present, stamens 4 or 5, often didynamous), Petunioideae (flowers bisymmetric, embryo slightly curved), Solanoideae (seeds flattened, embryo curved, often coiled), and Nicotianoideae (Cork superficial pericyclic fibres present or absent, stamens 4 or 5, of two lengths, embryo straight or curved). The grouping (Petunioi- deae (Solanoideae + Nicotianoideae)) is well supported, although the relationships between the more basal branches have only weak support, but Schwenkia is probably sister to the rest of the family (Olmstead et al., 1999). Family Sclerophylacaceae has been variously included under Solanaceae (Hutchinson, Cronquist, APG II), treated as distinct family (Takhtajan, Dahlgren), or considered unplaced (APweb) has been treated as subfamily Sclerophylacoideae of Solanaceae by Thorne (2003), who recognizes Browallioideae, Solanoideae and Goetzeoi- deae as other three subfamilies In subsequent revisions in 2006 and 2007, he recognises 7 subfamilies, adding Schizanthoideae, Petunoideae and Nicotianoideae. APweb (2008) likewise recognises 7 subfamilies, taking out Schwenckioideae doubtfully placed in Browallioideae by Thorne, Sclerophylaceae still unplaced. Olmstead et al. (1999) considered Schwenckia sister to rest of family, but Martins and Barkman (2005) using the nuclear gene SAMT (salicylic acid methyl transferase), found Schizanthus to be sister to the rest of the family, and with rather strong support, with Schwenkia weakly linked with Cestroideae. Furthermore, Wu et al. (2006) found a strongly supported grouping of [Solanoideae [Petunioideae + Nicotianoideae].

16. Rubiaceae

Madder family

650 genera, 13,000 species

Worldwide in distribution, but mainly distributed in the tropics and subtropics, especially the woody members.

Salient features: Mainly shrubs and trees, leaves opposite or whorled, often turning blackish when dry, stipules interpetiolar, colleters present in leaf axils, inflorescence cymose, flowers pentamerous, stamens 5, ovary inferior.

Major genera: *Psychotria* (1450 species), *Galium* (410), *Ixora* (370), *Pavetta* (360), *Hedyotis* (360), *Tarenia* (350), *Randia (240), Gardenia (240) and Mussaenda (190).*

Description: Trees (*Adina, Neolamarckia*) or shrubs (*Ixora, Gardenia*), rarely herbs (*Galium*), sometimes climbing (*Rubia*) with hooked hairs, rarely epiphytic (*Myrmecodia*) with large swellings on roots inhabiting ants, usually with Iridoids, raphide crystals common. **Leaves** opposite, with interpetiolar stipules which often become as large a leaves and thus forming whorled arrangement of leaves, simple, entire, often turning blackish when dry, with colleters in leaf axils. **Inflorescence** cymose, sometimes capitate (*Adina*), or solitary (*Gardenia). **Flowers** bisexual, actinomorphic, rarely zygomorphic (*Posoqueria*) epigynous, sometimes dimorphic (*Randia*). **Calyx** with 4-5 sepals, adnate to ovary, 5-lobed, lobes often very small, one sometimes enlarged and brightly coloured (*Mussaenda*). Corolla with 4-5 petals, *(rarely 8-10)*, united, tubular, rotate or funnel-shaped, valvate, imbricate or twisted. **Androecium** with 4-5 stamens, free, epipetalous, anthers bithecous, dehiscence longitudinal, introrse, pollen grains usually tricolporate. **Gynoecium** with 2 (rarely 1-many) united carpels, ovary inferior, rarely superior (Pugama) or semi-inferior (Synaptantha), bilocular (rarely 1-many locules) with 1-many ovules in each chamber, placentation axile (rarely apical or basal), nectar disc usually present above the ovary, style slender, stigma capitate or lobed. Fruit a berry, capsule, drupe or schizocarp; seeds 1-many, with small embryo, curved or straight, endosperm present or absent.

Economic importance: The family is economically important for being the source of coffee, quinine and a large number of ornamentals. Coffee is obtained from roasted seeds of *Coffea arabica* and *C. canephora*. Quinine, a remedy for malaria is derived from several species of *Cinchona*. Madder (Rubia tinctoria) was formerly cultivated for its red dye alizarin. Important ornamentals include Gardenia, Ixora, Hamelia, *Neolamarckia (cadamb tree)* and *Mussaenda*.

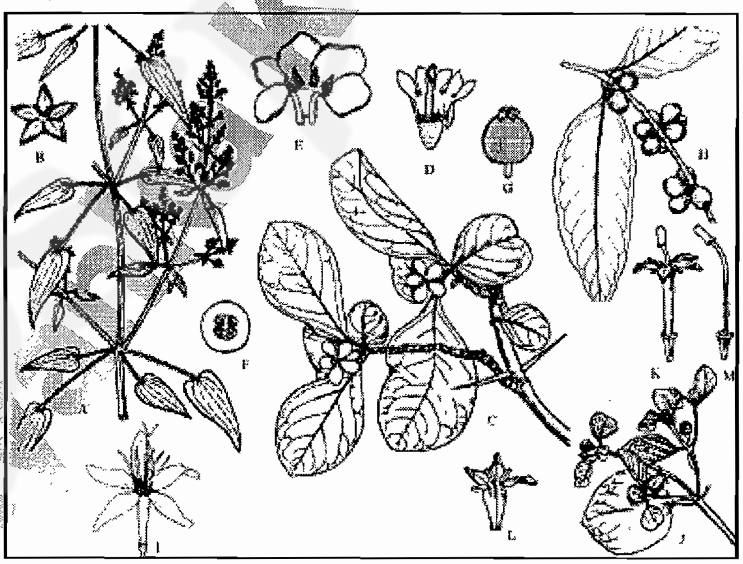

Figure-1: Rubiaceae. *Rubia manjith*. **A** Portion of plant with axillary inflorescences; **B**: Flower. Randia spinosa. **C**: Twig showing spines and flowers; **D**: Flower with corolla removed and calyx opened to show gynoecium; **E**: Corolla opened to show epipetalous stamens; **F**: Transverse section of ovary; **G**: Fruit. Coffea arabica. **H**: Portion of twig with fruits; **I**: Flower. Mitragyna parvifolia. **J**: Twig with globose inflorescences. **K**: Flower with mitraeform (head-gear) stigma; **L**: Corolla opened to show androecium; **M**: Flower with corolla removed to show style and stigma.

Phylogeny: Rubiaceae form a well-defined group which is clearly monophyletic as supported by morphology (*Bremer and Struwe, 1992*) and rbcL sequences (*Bremer et al., 1995*). Affinities of the family lie with Gentianales (Dahlgren, APG II, APweb; Thorne places under Rubiales also containing Gentianaceae and related families; Takhtajan under Rubiales next to Gentia- nales under Lamiidae—>Gentiananae) or Dipsacales (Cronquist—next to Dipsacales towards the end of Asteridae, Gentianales towards the beginning), both having opposite leaves and 2 carpels. The separation exclusively on the basis of ovary being inferior or superior, is slowly being abandoned as has also been done in the case of certain monocots such as Alliaceae, Agavaceae and Amaryllidaceae. The family is commonly divided into three subfamilies (Thorne, APweb): Cinchonoideae (mainly woody, raphides absent, seeds with endosperm, heterostyly absent), Ixoroideae (woody, raphides absent, pollination plunger-mechanism as in Asteraceae), Rubioideae (mainly herbaceous, raphides present in leaves, seeds with endosperm, heterostyly common). Molecular data (Fay et al., 2000a)b provide support for including *Dialy-petalanthus* (formerly placed under Dialy-petalanthaceae-Thorne, 1999) In Rubiaceae, under sub-family Ixoroideae (Thorone, 2003, 2006, 2007). Recent molecular studies basede on trnL-F and cpDNA data (Rova et al., 2002) and broadly based molecular data involving several taxa (Bremer et. al., 1999) suggest that Cinchonoideae and Ixoroideae are sister taxa.

17. Cucurbitaceae

Cucurbit or Gourd family

122 genera, 780 species

Mainly distributed in tropics and subtropics, in temperate regions often found in cultivation.

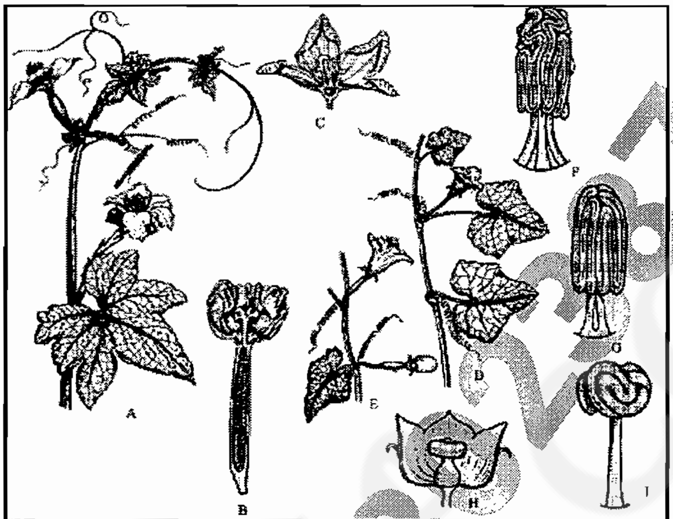

Figure-1: Cucurbitaceae. *Luffa cylindrica*. **A** Branch with male flowers on peduncle towards the base and solitary axillary **female** flowers towards the top; **B**: Vertical section of female flower; **C**: Vertical section of male flower. Coccinia cordifolia **D**: Branch with **male** flower; **E**: Branch with female flowers. **Stamen types**. **F**: Lagenaria with 3 stamens, 2 with bithecous anthers and 1 with monothecous anther; **G**: Cucurbita with anthers united into a column; H: Cyclanthera with anthers united into 2 rings running around the top; **I**: Sicyos with filaments as well as anthers united.

Salient features: Tendril climbing plants, leaves palmately veined, flowers unisexual, stamens 5, variously united, carpels usually 3, united, ovary inferior, fruit a berry or pepo.

Major Genera: *Cayaponia (60 species), Momordica (45), Gurania (40), Sicyos (40), Cucumis (30) and Cucurbita (27).*

Description. Climbing annuals with coiled tendrils, sometimes trailing (*Ecballium*), rarely xerophytic shrubs (*Acanthosicyos horrida*) or even trees (*Dendrosicyos*), vascular bundles usually bicollateral, often in two rings. **Leaves** alternate, simple, palmately veined, lobed or compound, rarely absent (*Acanthosicyos horrida*), stipules absent. **Inflorescence** cymose (*Bryonia)* or flowers solitary axillary (*Luffa female flower*), rarely in short racemes (*Luffa male flowers*), plants monoecious or dioecious. **Flowers** bracteate or ebracteate, unisexual, rarely bisexual (*Schizopepon*), actinomorphic, epigynous, with long hypanthium. **Calyx** with 5 sepals, more or less united, fused to ovary wall. **Corolla** with 5 petals, free (*Luffa, Lagenaria, Benincasa*) or united (*Cucurbita, Cucumis*), imbricate, commonly yellow or white. **Androecium** with 5 stamens, anthers monothecous, filaments free (*Luffa*) or connate, sometimes 4 of these fused in two pairs thus two stamens bithecous and third monothecous giving appearance of 3 stamens (*Coccinia*), rarely all five fused (*Cucurbita)*, pollen grains with 3 to many furrows. **Gynoecium** with 3 united carpels (*syncarpous*), unilocular with many ovules, placentation parietal, placentae enlarged intruding and often meeting in centre forming pseudo-axile placentation, ovary inferior, styles simple or 3-partite. **Fruit** a berry, pepo or capsule; seeds many, embryo straight, endosperm absent. Pollination mostly by insects. Dispersal by animals, capsules of Echinocystis open explosively.

Economic importance: The family is economically important for its food plants such as cucumber (*Cucumis sativus*), water melon (*Citrulus vulgaris*), loofah (*Luffa acutangula, L. cylindrica*), bottle gourd (*Lageneria siceraria)*, melon (*Cucumis melo*) and red pumpkin (*Cucurbita maxima)*. The dried fruit of Luffa yields bathroom sponge loofah. Species of *Bryonia, Cucumis*, *Momordica* are of medicinal importance.

Phylogeny: The family was earlier considered closely related to Passifloraceae and included under the same order. Hutchinson (1973) placed them under separate orders, Cucurbitales derived from Passiflorales through formation of unisexual flowers, parietal placentation, inferior ovary, and modification of stamens. The separation is followed by Takhtajan, Dahlgren, and APG group. Cronquist and Thorne preferred to retain these and other families under the same order Violales. Thorne (1999) placed Cucurbitaceae along with Begoniaceae and Datiscaceae under a separate suborder Begoniineae. Subsequently (2003, 2006, 2007)

he has added Tetramelaceae (earlier included under Datiscaceae). It is interesting to note that order Cucurbitales of APG II and APweb include the same four families along with a few more. Cucurbitaceae and Begoniaceae share the apomorphies of inferior ovary, strongly intruded placentae and imperfect flowers. Monophyly of Cucurbitales is supported by serological data and rbcL sequences. Cucurbitaceae is easily recognized and monophyletic, but of the two subfamilies commonly recognized only Cucurbitoideae is monophyletic, Nhandiroboideae (Zanonioideae) being paraphyletic. Renner et al., (2002) from the molecular studies multiple chloroplast loci. p. 169, concluded that Nhandiroboideae form an unresolved basal group.

18. Asteraceae

Sunflower or Aster family

(= **Compositae** Giseke)

1,532 genera, 23,790 species (largest family of flowering plants) Worldwide in distribution mainly in temperate and subtropical climates, mainly in mountain regions, also common in tropics.

Salient features: Usually herbs, lacking Iridoids, leaves usually alternate, stipules absent, inflorescence a capitulum with ray florets and disc florets (one type or both in a head), surrounded by involucre bracts (*phyllaries)*, calyx represented by pappus, anthers united forming a cylinder around style, style with two branches, fruit a cypsela (commonly called achene, although typical achene is formed from single carpel and superior ovary), ovary inferior.

Major genera: *Senecio* (1470 species), *Ver-nonia* (1050), *Cousinia* (600), *Eupatorium* (590), *Centaurea* (590), *Hieracium* (470), *Helichrysum* (460), *Saussurea* (300), *Cirsium* (270), *Aster (240), Bidens (210), Chrysanthemum (200), Crepis (200), Inula (200), Gnaphalium (140), Solidago (110), Helianthus (100), Carduus (90), Lactuca (90), Taraxacum (80), Tragopogon (70), Sonchus (50) and Calendula (30).*

Description: Usually herbs or shrubs, rarely trees (*Vernonia arborea; Leucomeris*) or lianas (*Vernonia scandens*), sometimes producing tubers (*Dahlia*, *Helianthus tuberosus*), usually storing inulin, laticifers usually present, rarely lacking, terpenoids usually present, usually sesqueterpene lactones, Iridoids absent. **Leaves** usually alternate and simple sometimes compound (*Dahlia*, *Artemisia*), rarely opposite (*Dahlia*) or whorled, stipules absent. **Inflorescence** a capitulum with broad receptacle containing disc florets (*discoid head-Ageratum*, *Vernonia*), ray florets (*ligulate head- Sonchus, Launaea*) or both type of florets with latter towards the periphery (*radiate head-Helianthus*, *Aster*), all types of heads having florets surrounded by involucre bracts (*phyllaries*), rarely capitulum with single floret (*Echinops*) with capitula arranged into globose heads. Flowers bisexual (usually disc florets and ray florets of a ligulate head) or unisexual (commonly ray florets in a ligulate head, which may even be sterile), actinomorphic (usually disc florets) or zygomorphic (usually ray florets), epigynous. **Calyx** absent or represented by pappus in the form of scales (Helianthus), bristles (Bidens), simple hairs (Sonchus) or plumose (*Carduus*). **Corolla** with 5 petals, united, tubular and 5-lobed (*disc floret*) or ligulate with 3-5 teeth (ray floret: sometimes also bilabiate). **Androecium** with 5 stamens with free filaments and united anthers (syngenesious) forming a tube around the style, epipetalous, anthers bithecous, dehiscence longitudinal. **Gynoecium** with 2 united carpels, unilocular a single ovule, placentation basal, ovary inferior, style with two branches. **Fruit** a cypsela (often called achene which typically, however, is formed from single carpel with superior ovary) usually with pappus at tip. Seeds 1, embryo straight, endosperm usually absent.

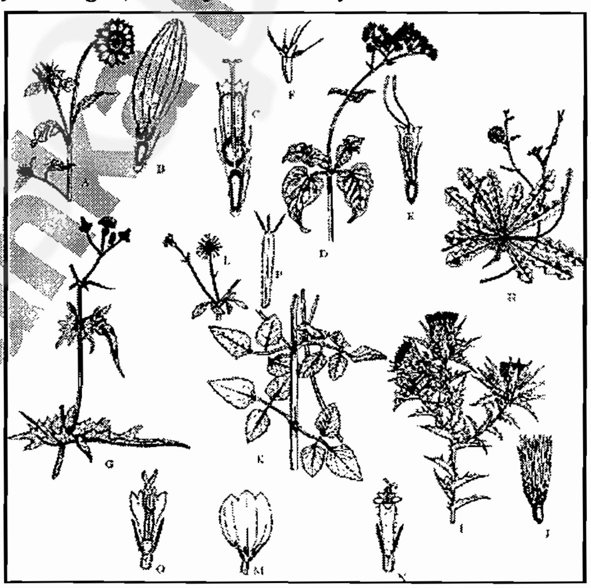

Figure-1: Asteraceae. *Helianthus annuus*. **A** Portion of plant with inflorescences, the capitulum with both ray florets and disc florets (radiate head); **B**: Vertical section of ray floret lacking androecium; **C**: Vertical section of disc floret. *Ageratum houstonianum*. **D**: Portion of plant with capitula in clusters, each with only disc florets (discoid head); **E**: Vertical section of disc floret; **F**: Achene with pappus consisting of 5 scales. **G**: Plant of Sonchus oleraceous with auricled leaves and capitula with only ray florets (*ligulate head*).

H: Plant of Launaea nudicaulis with ligulate heads. *Carthamus lanatus*. **I:** Portion of plant with spinose leaves and discoid heads; **J:** Capitulum with spiny involucre bracts. *Bidens chinensis*. **K:** Lower part of plant with pinnate leaves; **L:** Upper part with one flowering and one fruiting capitulum; **M:** Ray floret with three-toothed corolla; **N:** Disc floret; **O:** Disc floret with corolla partly removed to show androecium; **P:** Achene.

Economic importance: Compared to the number of species included, the family is of lesser economic importance. Common valuable ornamentals include species of Aster, Dahlia, Chrysanthemum, Gerbera, Helichrysum, Tagetus and Zinnia. A few food plants include Lactuca (*lettuce*), Cynara (*artichoke*), Helianthus (*sunflower oil*), and Cichorium (*chicory, added to coffee*). Safflower a red dye is obtained from Carthamus tinctorius. Latter is now more commonly cultivated for its seeds yielding safflower oil, used in cooking. Chrysanthemum cinerarie-folium is the source of natural insecticide pyrethrum.

Phylogeny: Interestingly Asteraceae in spite of huge size form a well-defined clade, easily recognizable and evidently mono- phyletic. The family is often considered related to Rubiaceae, Caprifoliaceae, Dipsacaceae, Valerianaceae, Campanulaceae and a few others. The first four are basically cymose and also differ in biochemical features. Stylidiaceae, Goode-niaceae and Brunoniaceae resemble the Asteraceae in being mostly racemose and in possessing inulin, but differ in biochemical features of taxonomic significance. Recent molecular studies (Bremer et al., 2002; Lundberg and Bremer, 2002) indicate that Asteraceae, Calyceraceae, Goodeniaceae and their sister group Menyanthaceae form a monophyletic group. All the four families are placed under Asterales by Thorne (1999, 2003). The relationships between the first three families are not very clear. The rbcL and ndhF (Karehed et al., 1999) and ndhF data (Olmstead et al., 2000) support Asteraceae and Calyceraceae as sister families whereas rbcL together with atpB and 18S rDNA (Soltis et al., 2000) support Goodeniaceae and Calyceraceae as sister taxa. A combination of morphological data, and rbcL, ndhF and atpB sequences provided a strong support for Calyceraceae and Asteraceae as sister groups (Lundberg and Bremer, 2002). Similar conclusion was also reached by the analysis of six DNA regions (Bremer et al., 2002).

The family Asteraceae is usually divided into three subfamilies: Barnadesioideae (style papillate, stigma lobed; cypsela with spines; lacks chloroplast DNA inversion found in other two subfamilies), Cichorioideae (Latex present, style branches long with inner surface stigmatic, acute; those with ray florets often separated into a distinct subfamily Lactucoideae) and Asteroideae (latex absent, both disc and ray florets). Thorne (2006, 2007) recognizes Carduoideae including Cichorioideae and Lactucoideae. He subdivides these three subfamilies further to include a total of 25 tribes in Asteraceae. Heywood had earlier (1978) recognized 17 tribes under two subfamilies Lactucoideae and Asteroideae. APweb (2003) recognizes 11 subfamilies including one undefined 'The Stifftia group'.

Subclass 11. Lamiidae

Superorder 1. Solananae

Order 1. Garryales (B)

Family 1. Garryaceae
2. Eucommiaceae
3. Aucubaceae
4. Oncothecaceae (B)
5. Icacinaceae (B)

2. Solanales

Suborder 1. Solanineae
1. **Solanaceae**
2. **Convolvulaceae**
3. Hydroleaceae (B)
4. Sphenocleaceae
5. Montiniaceae (B)

2. Boraginineae
1. **Boraginaceae**
2. Hydrophyllaceae
3. Lennoaceae
4. Hoplestigmataceae (B)

Superorder 2. Lamianae

Order 1. Rubiales
1. Gentianaceae
2. Loganiaceae
3. Gelsemiaceae
4. **Rubiaceae**
5. **Apocynaceae**

2. Lamiales
1. Oleaceae
2. Carlemanniaceae (B)
3. Tetrachondraceae (B)
4. Plocospermataceae (B)
5. Gratiolaceae (B)
6. Calceolariaceae (B)
7. Gesneriaceae
8. **Plantaginaceae** (B)
9. Pedaliaceae
10. Linderniaceae
11. Byblidaceae
12. **Lamiaceae** (B)
13. Paulowniaceae (B)
14. Orobanchaceae (B)
15. Phrymaceae
16. Nesogenaceae (B)
17. Schlegeliaceae (B)
18. **Verbenaceae** (B)
19. Martyniaceae
20. Petraeaceae (B)
21. Trapellaceae (B)
22. **Bignoniaceae**
23. Lentibulariaceae
24. **Acanthaceae**
25. Stilbaceae
26. **Scrophulariaceae**

Taxa Incertae Sedis

Haptanthus Goldberg & Nelson (1). Honduras.
Heteranthia Nesse & C.Mart. (1) Brazil.
**Pottingeria* Prain (1)
Pteleocarpa Oliver (1) W. Malesia.

* Under Hydrangeales-> Pottingeriaceae by Takhtajan

19. Musaceae

Banana family

2 genera, 40 species

Mainly wet tropical lowlands from West Africa to Pacific (Southern Japan to Queensland).

Salient features: Large herbs with pseudostems formed by leaf sheaths, leaves large with thick midrib, parallel venation, flowers unisexual, inflorescence subtended by large spathaceous bracts, corolla 2-lipped, stamens 5 (sixth rudimentary), carpels 3, ovary inferior, 3-locular, ovules numerous, fruit fleshy berry with numerous small black seeds.

Major genera: *Musa* (34 species) *and Ensete (6).*

Description: Large usually tree-like perennial herbs with pseudostems formed from overlapping leaf sheaths, with laticifers, rhizomatous. **Leaves** large, spirally arranged, simple, entire, margin often torn and blade appearing pinnate, venation parallel with stout midrib, sheathing at base. **Inflorescence** a panicle-like cyme with one or more spathes, axis arising from basal rhizome and growing up through pseudostem. **Flowers** unisexual (plant monoecious), male within upper bracts, female in clusters within lower bracts. **Perianth** 6 In two whorls, petaloid. Sepals 3, adnate to 2 petals, narrowly tubular, soon splitting on one side, variously toothed at apex. Petals 3, somewhat 2-lipped, 2 adnate with sepals, 1 free. **Androecium** with 5 fertile stamens and 1 forming staminode, adnate to petals, filaments free, anthers linear, bithecous, dehiscence by longitudinal slits, pollen sticky. Gynoecium with 3 united carpels, ovary inferior, 3-locular, ovules many, placentation axile, style filiform, stigma 3-lobed. **Fruit** elongated berry containing numerous seeds, fruits forming compact bunches; seed with copious and small embryo.

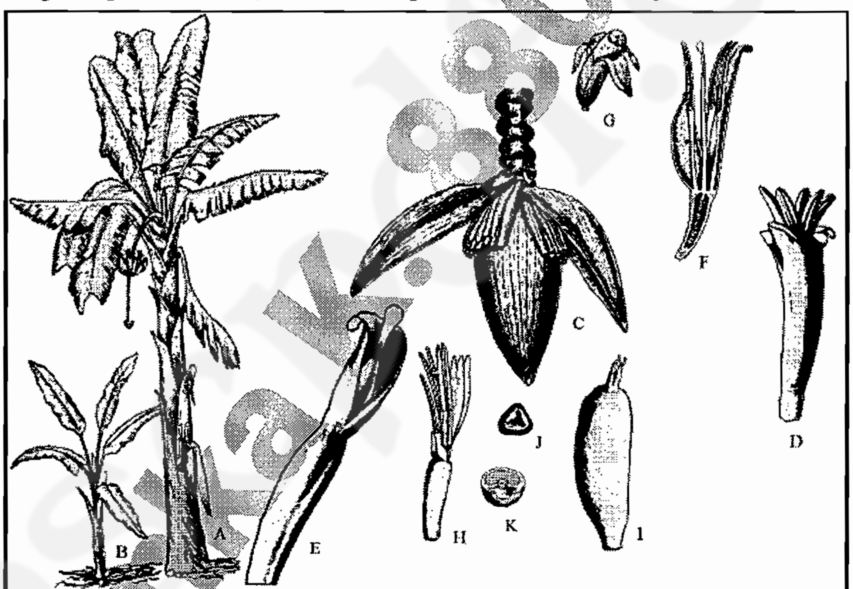

Figure-1: Musaceae. *Musa Paradisiaca.* subsp. *sapientum* (A-C, F, G) **A**: Plant with inflorescence and split old leaves; **B**: Young plant; **C**: Apical portion of inflorescence; **D**: Male flower of M. rubra; **E**: Female flower of M. rubra; **F**: Vertical section through bisexual flower; **G**: Fruit partially opened to show edible berry sliced at top. *Ensete edule.* **H**: Bisexual flower; **I**: Fruit; **J**: Seed; **K**: Transverse section of seed showing pit of hilum.

Economic importance: Banana (Musa paradisiaca subsp. sapientum) is a staple food in many tropical countries. Manila hemp or Abaca obtained from fibres of M. textilis is used in making ropes and cordage. Inset or Abyssinian banana (Ensete ventricosa) is cultivated for its fibre and for food; the stem pulp and young shoots are eaten cooked. Some dwarf cultivars of Musa (M. acuminata 'Dwarf Cavendish') are often grown as greenhouse plants in temperate climates.

Phylogeny: The family is usually placed in Zingiberales *(Cronquist, Dahlgren, APG II, APweb)* along with Cannaceae, Zingiberaceae, Marantaceae and other closely related families. The genus Heliconia, earlier placed in this family has been removed to a separate family Heliconiaceae (Thorne, APG II, APweb) or placed under Strelitziaceae (Heywood, 1978). Takhtajan included Musaceae under distinct order Musales. Thorne (2003, 2006, 2007) prefers name Cannales over Zingiberales for the broadly circumscribed order, divided into 6 suborders, Musaceae included under Musineae. Fossil record has been found in Eocene of W. North America.

20. Apocynaceae (Including Asclepiadaceae)

480 genera, 4,800 species

Mostly tropical and subtropical with a few species in temperate regions.

Salient features: Herbs shrubs or climbers, latex milky, leaves opposite or whorled, throat of corolla tube with scales, pollinia absent, ovary superior, fruit a follicle, seed with a tuft of hairs (Asclepiadoideae, formerly Asclepiadaceae separated by pollinia, anthers adnate to stigmatic disc, stigmas united into gynostegium).

Major genera: *Asclepias* (220 species), *Tabernaemontana* (220), *Cynanchum* (200), *Ceropegia* (140), *Hoya* (140), *Rauvolfia* (105), *Ervatamia* (80), *Allamanda* (15) *and Catharanthus* (5).

Description: Perennial herbs (*Catharanthus*), vines (*Cryptostegia, Daemia*), shrubs (*Calotropis, Nerium*), rarely trees (*Alstonia*), often fleshy (*Hoya*) or cactus-like (*Stapelia*), latex usually milky, Iridoids often present. **Leaves** simple, reduced or absent in some succulent species, opposite (*Calotropis, Catharanthus*) or whorled (*Nerium*), simple, entire, venation pinnate, reticulate, stipules absent, colleters often present at the base of petiole. **Inflorescence** dichasial or monochasial cyme, racemose or umbellate (*Calotropis*), sometimes solitary (*Vinca*), or axillary cymose pairs (*Catharanthus*). **Flowers** bisexual, actinomorphic, hypogynous, pentamerous, often coronate. **Calyx** with 5 sepals, distinct or basally connate, imbricate or valvate, often with glands (*colleters*) at base. **Corolla** with 5 united petals, the tube often short campanulate (*Calotropis*), salvershaped (*Catharanthus*) or funnel-shaped (*Thevetia*) and with contorted or valvate lobes. **Corona** of usually 5 scales or appendages arising from corolla throat (corolline corona: Nerium, Cryptostegia), or from stamens (*staminal corona: Calotropis, Asclepias*), coronal appendages nectariferous. **Androecium** with 5 stamens, filaments free (*Apocynaceae sensu str.*) or connate (*Asclepiadoideae except Cry-ptostegia*) anthers free with separate pollen grains (*Apocynaceae sensu str.*). In Asclepiadoideae anthers adherent to the stigmatic area forming a 5 angled disc gynostegium (gynandrium), pollen agglutinated within the anther sacs to form waxy pollinia (corpusculum or gland joining together two pollinia one each from adjacent anthers with the help of caudicles to form translator, an adaptation for insect pollination); pollen grain tricolporate or biporate or triporate. **Gynoecium** bicarpellary of two apically united carpels, unilocular ovaries, marginal placentation, ovules 2 or more, unitegmic, styles 2, stigma 1, calyptrate (*Catharanthus*), dumb-bell shaped (*Nerium*), or 5 lobed and fused with anthers to form gynostegium (*Cabtropis*), carpels sometimes united by ovaries with axile placentation (*Thevetia, Allamanda, Carissa*). **Fruit** etaerio of 2 follicles (*Nerium, Calotropis*), sometimes drupe (*Thevetia*), capsule or berry; seeds usually numerous, flattened and comose with long silky hairs. Pollination by insects, helped by special translators in Asclepiadoideae. Dispersal mostly by wind, aided by hairs.

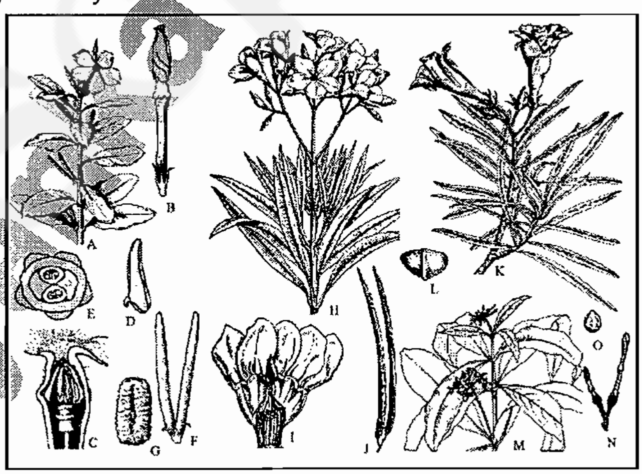

Figure-1: Apocynaceae. *Catharanthus roseus*. **A:** Portion of plant with flowers and fruits; **B:** Flower bud showing twisted corolla with a long tube; **C:** Vertical section of flower from corolla throat showing free epipetalous stamens and calyptrate stigma; **D:** Anther with dorsal fixation; **E:** Transverse section of flower passing through ovary showing sepals, corolla tube 2 lateral nectaries and 2 free ovaries; **F:** Pair of follicles; **G:** Seed. *Nerium indicum*. **H:** Branch with whorled leaves and terminal inflorescence; **I:** Corolla opened to show corona of scales and anthers with tailed appendages forming single twisted hairy appendage; **J:** Pair of follicles. *Thevetia nerifolia*. **K:** Branch with subopposite and alternate leaves and large funnel-shaped

flowers; **L**: Drupe fruit. *Rauvolfia serpentina*. **M**: Portion of plant with inflorescences in flower and fruit; **N**: Flower buds with twisted corolla; **O**: Seed.

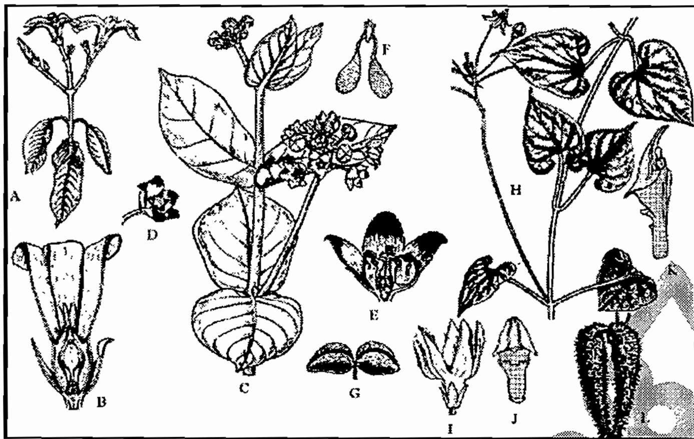

Figure-2: Apocynaceae, Subfamily **Asclepiadoideae**. *Cryptostegia grandiflora*. **A**: Branch with terminal inflorescence; **B**: Vertical section of flower with corolloin corona and gynostegium. *Calotropis procera*. **C**: Portion of plant with umbellate inflorescences on axillary peduncles; **D**: Flower with purple-tipped corolla; **E**: Vertical section of flower with staminal corona and broad gynostegium and free ovaries; **F**: Translator with 2 pollinia joined by caudicles to common corpusculum; **G**: Pair of follicles. *Pergularia daemia*. **H**: Portion of plant with inflorescence; **I**: Flower; **J**: Flower with calyx removed and corolla lobes cut to show corona and staminal tube; **K**: Stamen and corona in side view; **L**: Pair of follicles covered with bristles.

Economic importance: *Nerium* (oleander), *Catharanthus* (Madagascar periwinkle), *Asclepias* (milkweed), *Hoya* (wax plant), *Stapelia* (carrion flower), *Plumeria* (frangipani) and Tabernaemontana are grown as ornamentals. Nerium and Thevetia are poisonous (can be fatal). Roots of Rauvolfia serpentina yield re-serpine used as tranquillizer for patients suffering from schizophrenia and hypertension. Catharanthus provides antileukaemic drugs. Latex from Plumeria used for healing toothache. Low quality down is obtained from seeds of several species. Pitcher like leaves and roots of Dischidia chewed with betel. Rubbervine (*Cryptostegia*) is also as caoutchouc or rubber source. Tubers of Ceropegia are edible. Stem fibre of Calotropis and Leptadaenia Is used for cordage. Asclepias is a livestock poison.

Phylogeny: For a long time Apocynaceae was considered to be closely related but distinct from Asclepiadaceae, latter with pollinia, gynostegium and usually staminal corona (Bentham and Hooker, Engler and Prantl, Hutchinson, Cronquist, Dahlgren). The family Asclepiadaceae was merged with Apocynaceae by Thorne (1983) and practice was followed by Takhtajan (1987, 1997), Judd et al., (2002), APG II and APweb. The separation of Asclepiadaceae as distinct family would lead to paraphyletic Apocynaceae (Judd et al., 1994; Endress et al., 1996). The family Apocynaceae is appropriately divided into 5 subfamilies (Thorne, 2000, 2006, 2007): Rauvolfioideae (*Plumerioideae*), Apocynoideae, Periplocoideae, Secamonoideae and Asclepiadoideae. The generic limits are not clearly resolved. According to Sennblad and Bremer (2002), both Rauvolfioideae and Apocynoideae may be quite wildly para-phyletic. The position of the Periplocoideae as sister to Secamonoideae + Asclepiadoideae is also uncertain (***Potgeiter & Albert, 2001; Sennblad & Bremer, 2002)***.

The family is usually placed in Gentianales, but Thorne has merged this order with broadly circumscribed Rubiales. Dahlgren and APG-II classification prefer the name Gentianales for the broadly circumscribed order.